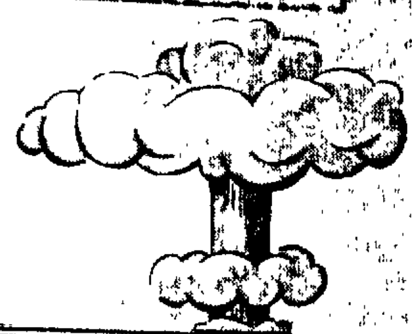
Operation

JANGLE

NEVADA PROVING GROUNDS
OCTOBER-NOVEMBER 1951

BIOLOGICAL HAZARDS



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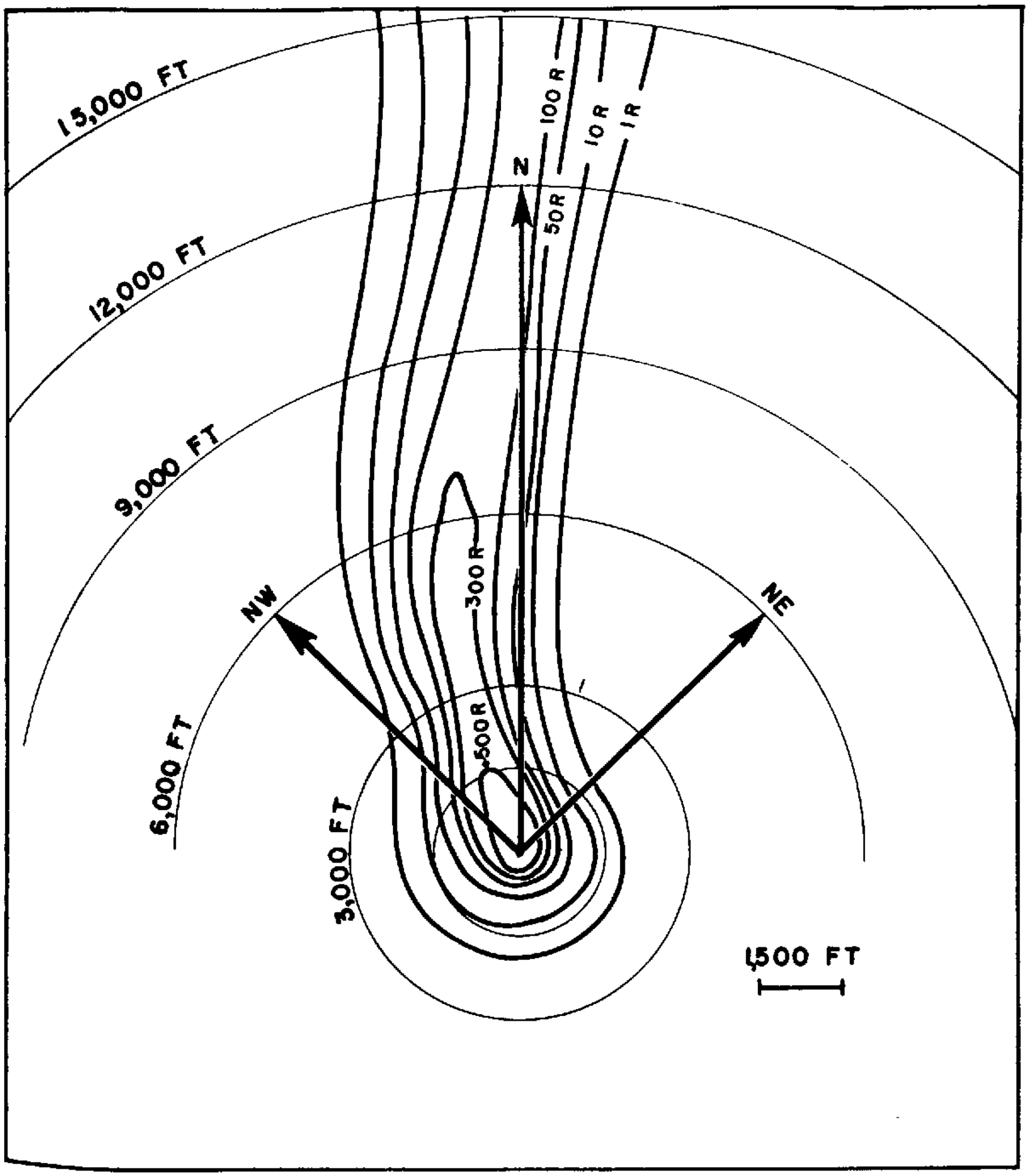

Fig. 3.4 Radial Lines Along which Early-time Fall-out Stations were Located with Respect to the Gamma-ray Dose-rate Contours Plotted at 1 hr Following the Surface Shot. Contours Given in r/hr.

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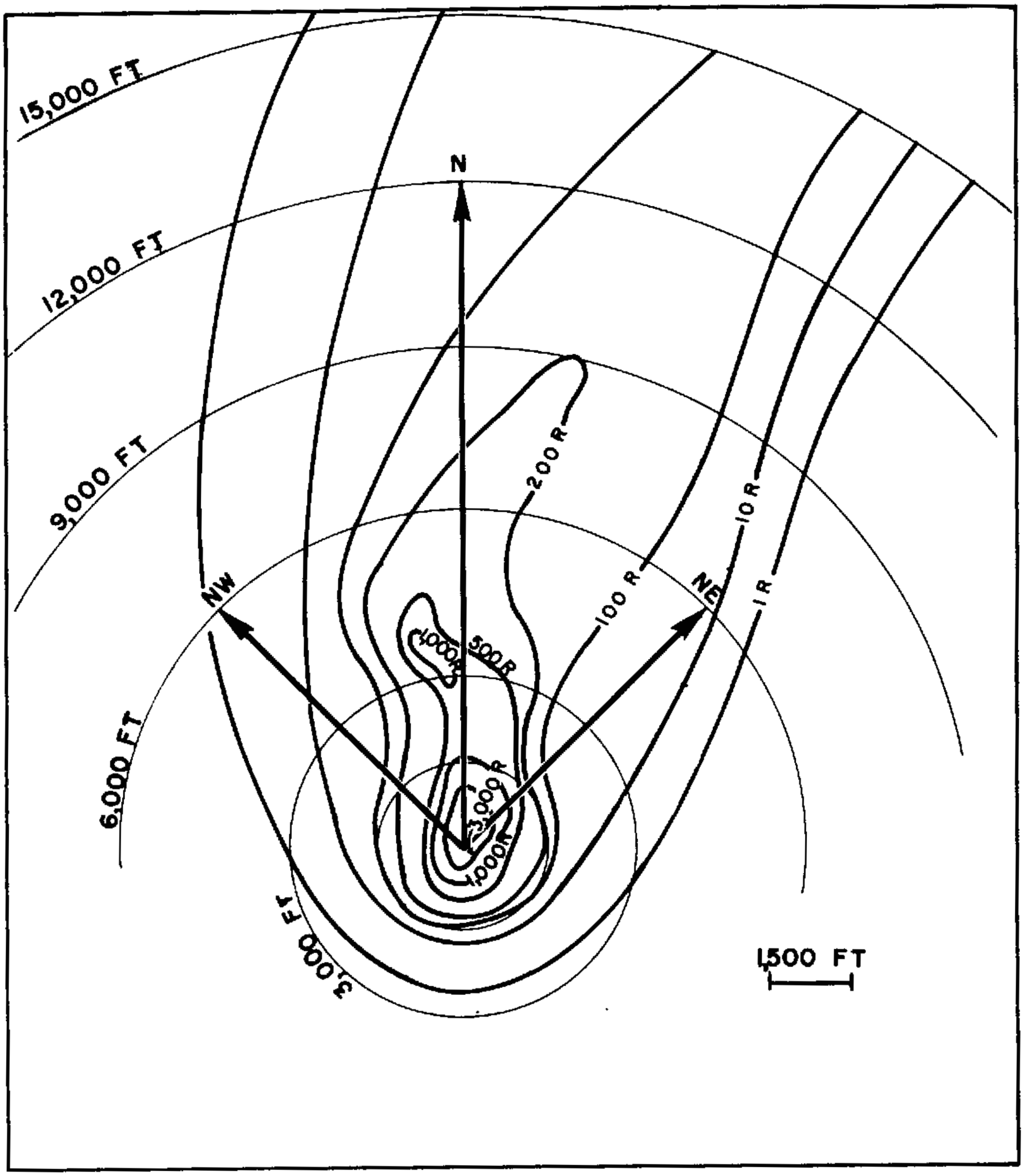

Fig. 3.5 Radial Lines Along which Early-time Fall-out Stations were Located with Respect to the Gamma-ray Dose-rate Contours Plotted at 1 hr Following the Underground Shot. Contours Given in r/hr.

considered rather than the maximum ratio observed.

From Table 3.8 the average ratio of beta-ray ionization for the underground post-shot exposures is approximately 19. It is of interest to see what this average ratio for the scanning packs would be when extrapolated to 1.5 in., the distance from contamination of the fall-out packs. Beta- and gamma-dose rate data measured as a function of height above the contaminated ground surface allowed the ratio at 18 in. to be extrapolated to a corresponding ratio at 1.5 in. This extrapolation gave a value of greater than 100 at 1.5 in. It can be seen from Tables 3.4 through 3.6 that none of the early-time fall-out measurements made at a distance of 1.5 in. gave a ratio in excess of 24. Were both the scanning and the fall-out packs exposed to exactly the same type of radiation, this difference would not exist.

The fall-out packs, in addition to the ionization received from the residual fission products, were further subjected to early gamma and cloud gamma radiation. On this basis the gamma-ray dose received from these two effects was at least four times greater than the subsequent gamma-ray dose received from the residual contamination deposited in the vicinity of the film packs. Thus, for the early-time fall-out packs, even though the beta-to-gamma ratio from the residual contamination could produce a beta-to-gamma dose of approximately 100, the radiation from the early gamma plus cloud gamma reduced the ratios obtained to no larger than 24 to 1 over the periods involved.

CHAPTER 5

CONCLUSIONS

5.1 CONCLUSIONS

The important properties of beta- and gamma-radiation fields arising from fission-product contamination can be summarized as follows:

5.1.1 Effective Gamma-ray Energy

1. The effective gamma-ray energy measured at times ranging from 5 to 340 hr following the surface shot, and at distances varying between 3,200 and 150 yd from ground zero, ranged between 84 and 140 kev.

2. The highest energies were observed in the vicinity of the crater and also at early times following the burst. At other localities and times the energies were less and varied in a random manner.

3. The effective energies for the surface shot were similar to those obtained for two tower shots at Operation GREENHOUSE, where the energies ranged between 83 and 127 kev.

4. The effective gamma-ray energy measured at times ranging from 5 to 97 hr following the underground shot, and at distances varying between 2,300 and 850 yd from ground zero, ranged between 113 and 144 kev.

5. The underground burst produced a circular area of fine dust about ground zero at a radius of approximately 1,700 ft. Within this circle the energy was distinctly higher, averaging 140 kev, as compared to 115 kev outside the circular area. The difference in energy within the two areas is due to geometry rather than any change in chemical composition of the fission products.

6. The effective energy of the combined early gamma plus cloud and early fall-out gamma radiation following the surface shot ranged between 430 and 565 kev.

7. The effective energy of the combined early gamma plus cloud and early fall-out gamma radiation following the underground shot ranged from 376 to 430 kev.

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5.1.2 Equivalent Maximum Beta Energies

1. The equivalent maximum beta energy as determined from film pack measurements on early-time fall-out contamination was no greater than 1.7 Mev when averaged over an exposure period from time zero until 24 hr following the surface shot.

2. For the underground shot the equivalent maximum beta energy of the early-time fall-out contamination was no greater than 2.0 Mev when averaged over an exposure period from time zero until 70 hr following the shot.

3. Since the beta energies presented for these two shots are averaged over the time intervals involved, somewhat higher equivalent maximum energies are to be expected within the first hour post shot. Other considerations indicate the energy within the first hour would not be much greater than 2 Mev.

4. A single post-shot measurement of the equivalent maximum beta energy at a height of 18 in. above the contaminated ground surface gave a value of 2.0 Mev for the surface shot. This exposure covered a 24-hr period starting at 4.5 hr post shot.

5. A series of post-shot measurements at a height of 18 in. gave an equivalent maximum beta energy of 1.7 Mev for the underground shot.

5.1.3 Beta-to-gamma Ratio

1. The ratio of beta-ray to gamma-ray ionization on the surface of film packets located from 3,500 to 12,000 ft north of ground zero ranged from 2 to 14 for the surface shot. No significant ratios were observed closer than 3,500 ft. The ratios are for an integrated exposure from time zero until 27.5 hr post shot.

2. The ratio of beta-ray to gamma-ray ionization on the surface of film packets located from 1,700 to 5,000 ft north of ground zero ranged from 6 to 20 for the underground shot. From 6,000 to 10,000 ft all films were overexposed. At 11,000 and 12,000 ft the two farthest locations at which films were placed, ratios of 22 and 24 were measured. The ratios are for an integrated exposure from time zero until 70 hr post shot.

3. The ratio of beta-ray to gamma-ray ionization made at a height of 18 in. above the ground following the surface shot and at 3,200 ft northwest of ground zero was 4. Due to adverse weather conditions this was the only exposure made.

4. The ratio of beta-ray to gamma-ray ionization made at a height of 18 in. above the ground at various locations following the underground shot averaged 19.

5. Extrapolating the beta-to-gamma ratio obtained from the post-shot packets at the underground shot to a distance of 1.5 in. gave a ratio of approximately 100 to 1. This is in contrast to a maximum ratio of 24 to 1 measured at the same distance by means of the fall-out packets. The difference exists because the fall-out packets were subjected to components of gamma radiation arising from the early-gamma plus cloud-gamma radiation which contributed no simultaneous beta radiation. Thus, even in the most highly contaminated areas of the underground shot, the fall-out film packets saw a component of gamma radiation which was 4 times greater than the gamma radiation received from the fission products deposited over the films.

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OPERATION JANGLE

PROJECT 2.7

BIOLOGICAL INJURY FROM PARTICLE INHALATION

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TABLES

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ABSTRACT

Mongrel dogs and sheep were exposed at 2500, 5000, and 8000 feet from surface and underground zero. The purpose of the exposure was to assess the hazard due to inhalation of the dust associated with surface and underground atomic detonations; and to compare the internal and external doses obtained in the exposed test animals.

Animals were sacrificed at from H + 10 to H + 24 hours, and at D + 2, D + 4, D + 9, and D + 70 days. Dry ashed homogenates of lung, liver, spleen, kidney, blood, bone, urine and gut contents were assayed for radioactivity. Representative pieces of soft tissues were fixed by a freezing dehydration method for the preparation of autoradiographs. Samples of bone were wet ashed and assayed for their radioactivity.

Radioactivity in tissues taken from animals exposed during the surface shot was extremely low and total body amounts of radioactive materials found at the time of sacrifice were estimated to range between 0.06 μc and 2.13 μc. Total body activity for animals exposed during the underground test ranged between 2.22 μc and 31.1 μc. Integrated internal dosage due to β emission ranged from 0.10 rep to 0.43 rep. Dosage for dog lungs due to β emission ranged between 0.25 and 7.03 rep and between 0.19 and 8.83 rep for sheep lungs. Tissue radioactivity had fallen below limits of detection in all animals by D + 9 following the underground shot. Embryonic tissues and associated fluids contained just detectable activity.

Three types of radioactive particles were detected in autoradiographs of lung tissue. One of these particles was a pure α emitter of 5 mev energy and was probably Pu^{239}. A second type of active particle emitted α and β particles while a third was a pure β emitter of indeterminate energy. Autoradiographs of soft tissue other than lungs showed no blackening. A few bone samples contained sufficient activity to cause some blackening on Ilford plates after 29 days of exposure. No evidence of α activity could be detected in bone samples. Radiochemical analysis of the femurs strongly indicated that their activity was due to Ba^{140} and Sr^{90}.

Amounts of activity taken up by the combined action of inhalation and ingestion in animals exposed to the dust associated with either type of detonation were not physiologically significant. The mixture of materials thus taken up was undetectable in tissues of animals sacrificed 4 days after the surface shot and 9 days after the underground shot. It is calculated that the underground detonation of a 20 KT weapon would not result in a short term inhalation and ingestion hazard to dogs and sheep exposed under conditions comparable with those prevailing during the JANGLE underground test.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVES

Objectives of the study of the biological injury from particle inhalation, project 2.7, are as follows:

1. To estimate the inhalation hazard associated with the two types of detonations in Operation JANGLE.
2. To determine the relationship between internal radiation dose and external dose in order to evaluate their relative importance in the two types of detonations.
3. To estimate the inhalation hazard from similar detonations of greater yield.

1.2 HISTORICAL AND THEORETICAL CONSIDERATIONS

Under laboratory conditions an evaluation of the hazards resulting from inhalation of radioactive dusts requires that certain fundamental data be available. Not all of these data are obtainable under field conditions. Retention of particulate matter by the lungs is a function of particle size; respiratory pattern, including the rates of flow of air into and out of the lungs; the respiratory rates; and particle concentration in the inhaled air.

Particle size markedly influences depth of penetration and therefore lung retention of the active materials. Van Wijk demonstrated that 25% of 0.2 μ particles were removed by breathing compared to 80% removal of 2 μ particles. Depth of penetration increases with decreasing particle size as shown by Hatch but particles under 0.5 μ in diameter, tend to be flushed out in the exhaled air. Particles 0.5 μ to 5 μ in diameter, assuming no aggregation are more likely to reach the alveoli and be retained in the lung than are either larger or smaller particles. Dygbert demonstrated that intratracheal injection of suspensions of U_3O_8 particles having a size range of 0.2 μ to 10 μ gave a physiological response that varied inversely with the particle size.

From the foregoing evidence it has been assumed in this study that the inhaled particles of physiological significance lie in a size range between 0.2 μ and 5 μ, particle size measurement in the inhaled air

under field conditions being impractical. Particles larger in diamete: than 5 μ would not have reached the alveoli in the exposed animals while those below 0.2 μ would be expected to have been flushed out during the exhalation phase of the respiratory cycle.

It is obvious that the duration of exposure to dusts of high concentration will appreciably influence the amount of particulate matter taken into the lungs. Acute exposure of 5 to 30 minutes to suspension: containing P^{32} tagged bacterial spores 0.5 μ to 1.5 μ in diameter were shown by Taplin to result in significant contamination of the lung parenchyma for as long as 72 hours. The exposure of the animals in bot the surface and the underground tests of Operation JANGLE are consider of an acute nature the duration of which is about 30 minutes.

The respiratory rates and patterns of the exposed animals during this interval of time had to be taken as average for the species, sinc no data were obtained on these factors during the test. With human subjects, and flow rates between 60 and 18 liters per minute, Landahl found that retention values were larger at larger flow rates but that even at the lowest flow rates the maximum retention occurred with parti cles 0.25 μ to 0.55 μ in diameter. Ventilation volumes for the animal: during the exposure period will be assumed to be those which have appe ed in the literature (see studies by Morgan, Grodins, Comroe and Gardner for dogs; Kibler and Lee for sheep). Dogs, weighing between 8 kg and 15 kg respire at the mean rate of 18 respirations per minute an have an average minute volume of 4 liters. Ventilation volumes in shee vary widely but may be taken to average 20 liters per minute (range 13 to 25 liters). Respiratory rates per minute for sheep fluctuate betwe 35 and 44 at 3° to 23°C. Employing these data the total volumes of ai passing into the lungs of the dogs and sheep during the 30-minute exposure are calculated to be 120 liters and 600 liters respectively.

Only about 60% of the particulate matter of 5 μ diameter and bel is retained in the respiratory tract. Hatch presents data showing tha over-all lung retention of particles of less than 1 μ to about 4 μ range between 50% and 70%. Brown, in reviewing several studies, found lung retention to be about 55% for 1 μ particles and about 30% for 5 μ parti cles.

Calculation of total theoretical uptake by the test animals duri a 30-minute exposure following the underground test may be made, using data derived from air-borne particle studies.[1] Median diameter of gro samples in three hour collections on thermal precipitators was 0.22 μ. The radioactive particles of the range 0.5 μ to 8 μ in such samples

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1. The authors are grateful to Mr. I. G. Popoff, Technical Coordinato N.R.D.L., for the data used in these calculations.

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were found[1] to have a median diameter of 1.4 μ after autoradiographic and optical examination. For the three hour collection period the average mass concentration for 0.5 μ to 8 μ radioactive particles was calculated to be 0.013 μ gm per liter. An 8 kg dog, breathing at the rate of 18 times per minute and exposed to this concentration of material for 30 minutes following the underground detonation (omitting consideration of matter less than 0.5 μ) could have accumulated within its lungs a maximum of 0.93 μ gm. In a similar exposure a 45 kg sheep could have obtained 5.8 μ gm of radioactive particulate matter 0.5 μ to 8 μ in diameter.

From the three-hour collection data the concentration at H + 1 hour of air-borne radioactivity carried by particles in the 0.5-8 μ range is about 100 μc per μ gm. Data from the final report in project 2.5a-2 show that a maximum of 4-6% of the total activity is carried on particles below 20 μ in diameter. Of this amount approximately 1% is carried on particles of less than 1 μ diameter. In addition differential fall-out data obtained in project 2.5a-2 indicate that periods of high concentration of short duration occurred at various stations and therefore the reported concentrations of activity are only approximate. Furthermore the average specific activity of dust particles from collector samples at 10 hours, although constant up to about 3.5 μ in diameter, dropped markedly and remained low in particles up to about 9 μ in diameter.[2] Assuming 1.5 μc per liter as an average value for the particulate matter taken up and retained by both sheep and dogs at the end of 30 minutes, theoretical total uptake of activity for an 8 kg dog would be 180 μc (0.022 μc/gm) and 900 μc (0.020 μc/gm) for a 45 kg ewe. This amount of activity is of the order of 10 to 100 times higher than the total activity determined from measurements of radioactivity in animals exposed during the underground test as will be indicated later, in a discussion of the results.

1. Samples from 2.5a stations 108 and 120.
2. The authors are grateful to Lt. Col. Charles Robbins (project 2.5a) for these data.

CHAPTER 2

TEST RESULTS

2.1 EXTERNAL GAMMA DOSAGE, MORTALITY AND SACRIFICE TIMES FOR ANIMALS EXPOSED DURING THE SURFACE AND UNDERGROUND TESTS

2.1.1 External Gamma Dosage - Surface Test

Tables 2.1 and 2.2 present a schematic arrangement of the layout of the animal exposure stations (12 ewes, 15 dogs) during the surface test and permit a comparison to be made between the location of the stations on their respective arcs and total external radiation dosage received during the exposure. Animal exposure procedures are discussed in Appendix A. Animal stations for the surface test were spaced at intervals of 175, 300 and 400 feet for the 2500, 5000 and 8000 foot arcs respectively. Standard foxholes[1] located along a line 45° east of North at 2500 and 5000 feet from surface zero were constructed. Four animals (2 dogs and 2 ewes) were placed in the foxholes at 2500 feet while 3 animals (1 dog and 2 ewes) were in foxholes at 5000 feet.

National Bureau of Standards film dosimeters placed in pairs within 10 feet of surface animal stations and inside the foxhole stations showed that gamma dosage was less than 10 r at all positions on the 5000 and 8000 foot arcs. Animals exposed at the surface stations at 2500 feet received doses ranging from 265 r on the east end to a maximum of 300 r near the center of the arc. Animals exposed in foxhole positions at 2500 feet received external doses ranging about 3.5% of the dosage received by adjacent surface exposed animals. Table 2.2 gives the distribution of the gamma dose measurements within the foxholes and shows that the dosage at the region of the animals' bodies was less than 10 r at both 2500 feet and 5000 feet.

2.1.2 External Gamma Dosage - Underground Test

Twenty ewes and 23 dogs were exposed to the underground detonation. Tables 2.3 and 2.4 present a schematic plan of the layout for animal stations used during this test. Animals which had been exposed at 5000 feet and 8000 feet from surface zero and which had not been sacrificed were reused for the underground test because gamma doses received during the prior exposure were negligible and radioactive contamination was found to be below significance. Late changes in the layout and number of stations made it impossible to instrument all

1. See Appendix A for dimensions of foxholes.

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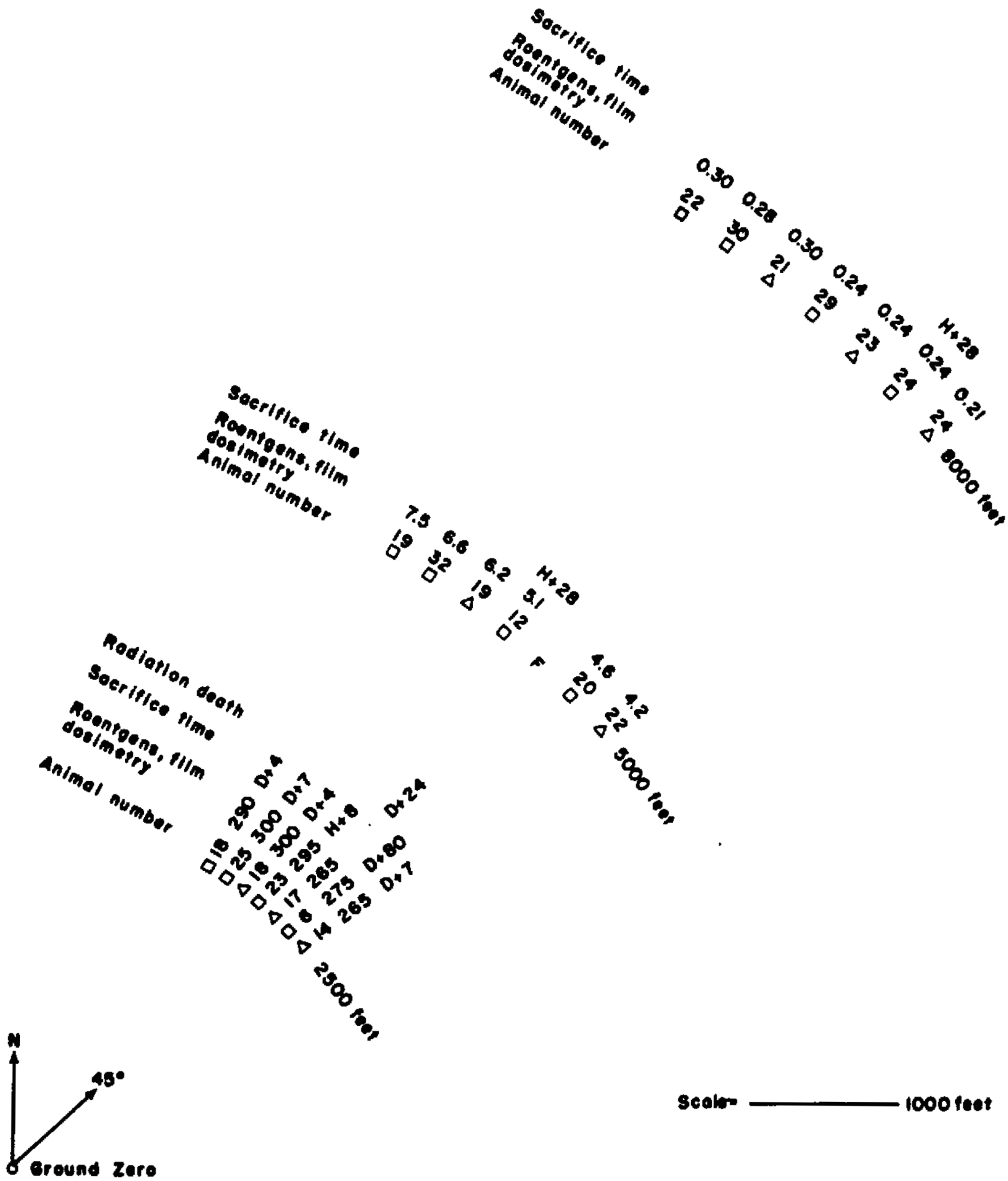

Table 2.1. Animal Exposure Stations, Surface Test; △ Sheep, □ Dogs, F Indicates Foxhole Positions

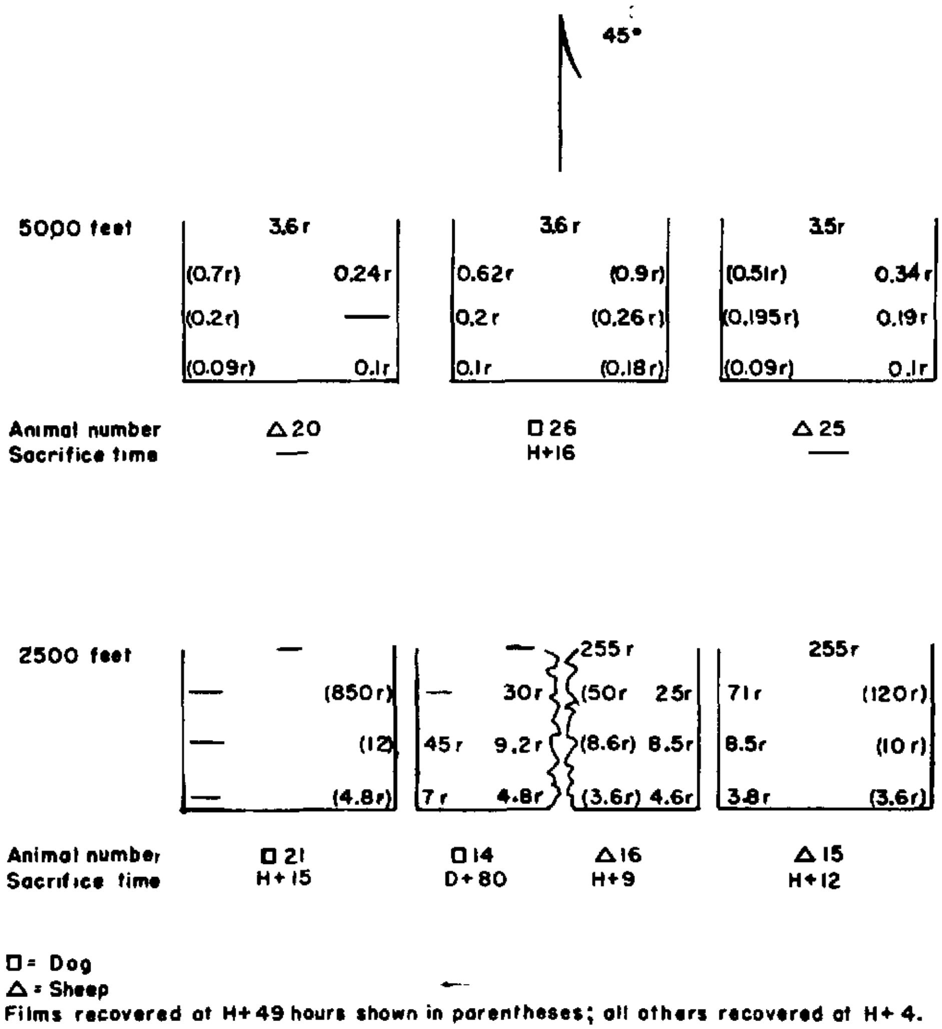

Table 2.2. Foxhole Dosimetry, Surface Test

stations with film dosimeters. Independent measurements made with Polaroid self-developing papers[1] attached at the back of each animal showed that those stations not otherwise instrumented received doses in excess of 400 r. Total external dose was estimated from 6 hour and 24 hour total dose data of project 2.1a[2] for the animal exposure stations which were not metered by film packets and these doses are

1. Polaroid Corporation, Cambridge, Mass., paper designation-DT-65-/PD.
2. L. Costrell, Operation JANGLE, Project 2.1a; Gamma radiation as a function of Time and Distance; National Bureau of Standards, 1952.

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shown in parentheses in Table 2.3. Data from 2.1a station No. 123 indicate a 24 hour dose of 360 r while at station No. 124 the total dose was 702 r at 6 hours. An interpolation of the 24 hour total dose

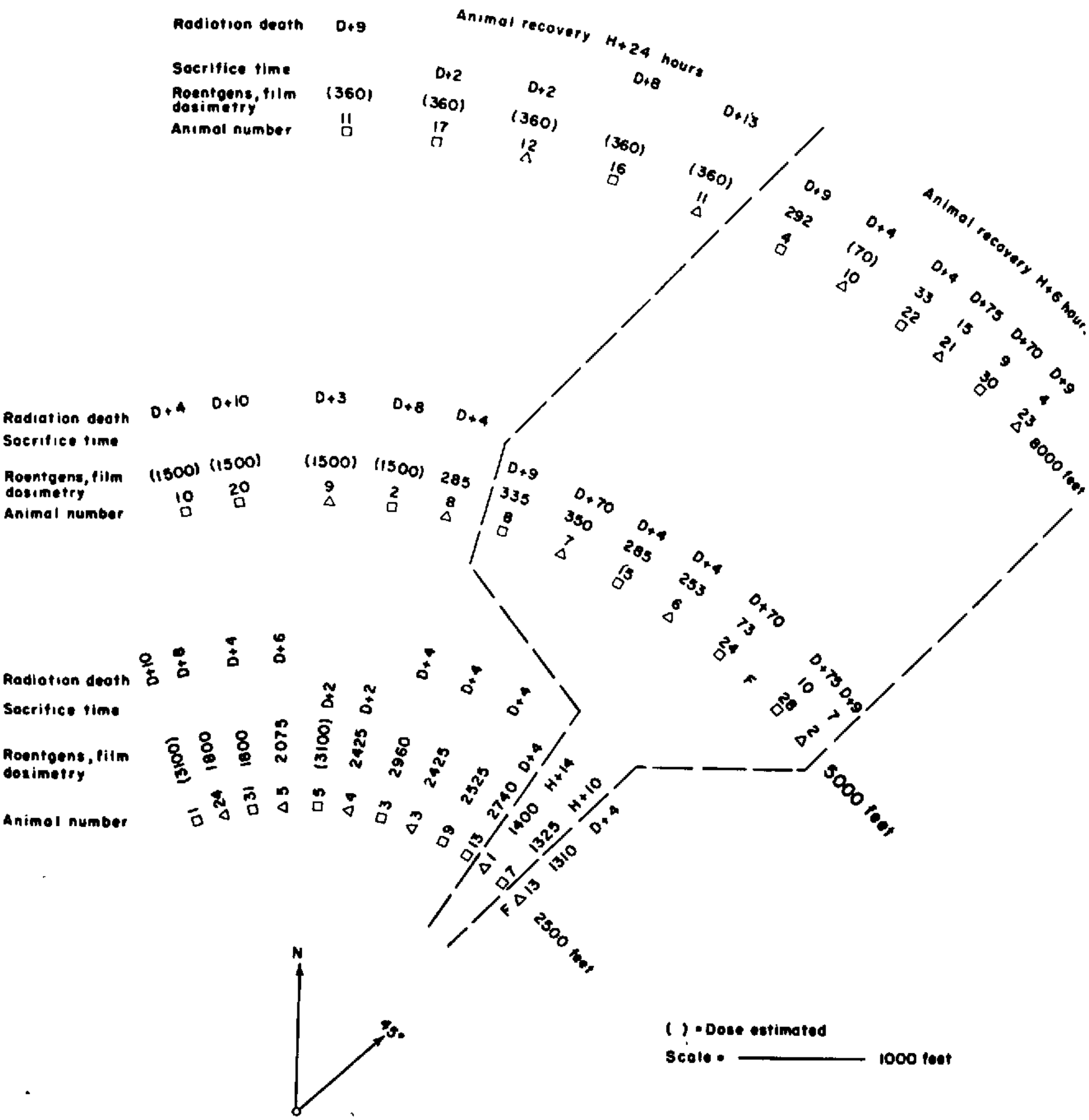

Table 2.3. Animal Exposure Stations, Underground Test; △ Sheep, □ Dogs, F indicates Foxhole Positions

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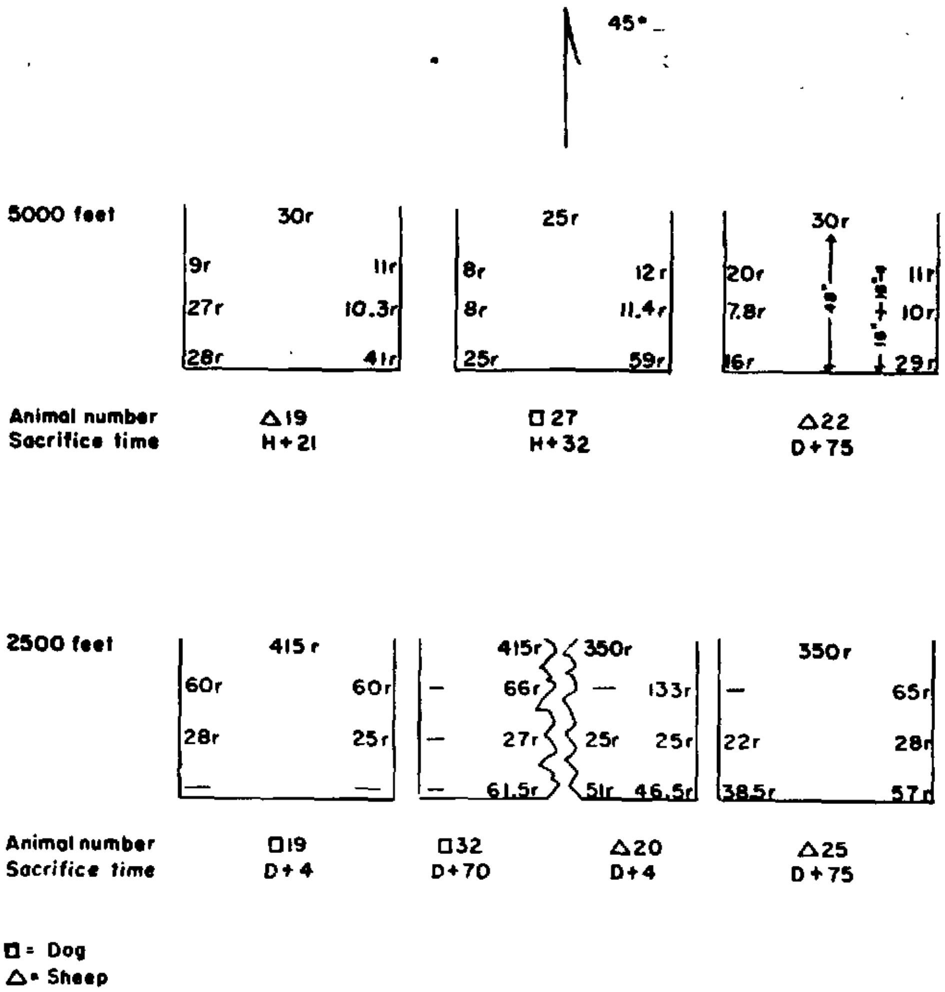

Table 2.4. Foxhole Dosimetry, Underground Test, Symbols as in Table 2.3

data from 2.1a stations No. 120 and No. 114 indicate that the animals toward the north end of the 5000 foot arc may have received about 1500 r. This estimate results in a large difference in dose between dog No. 2 and ewe No. 8. However, the 10 hour, 1000 r contour falls approximately between these two exposure stations. It is suspected that the film dose given in Table 2.3 for ewe No. 8 and dog No. 8 are too low. A similar discrepancy occurs at the north end of the 2500 foot arc in which the last animal received a dose of the order of 3100 r as determined from an interpolation of the results obtained at 2.1a stations No. 102 and No. 108. It is therefore suggested that the doses determined by film dosimetry for dog No. 31 and ewe No. 5 are too low since they are clearly inconsistent with the measurements made in project 2.1a.

External gamma dosages were generaly higher for corresponding stations in the underground test than they were in the surface test. Maximum doses from film measurements for surface exposed animals at 2500 feet ranged from 1800 r near the north end of the arc, 2960 r about the center to 1310 r on the east. Doses ranged between 7 r and 350 r along the 5000 foot arc and between 4 r and 292 r on the 8000 foot arc. Film dosimeters were recovered simultaneously with the animals and recovery was completed for all animals by H + 24 hours. Foxhole exposed animals at 2500 feet received only about 4% of the dose received by adjacent surface exposed animals. At 5000 feet the dosage fell off steeply towards the south at about the 45° line so that surface and foxhole animals appeared to receive nearly similar doses.

2.1.3 Mortality of Animals Exposed During the Surface and Underground Tests

Sacrifice of animals at intervals following exposure in both the surface and the underground test prevented accurate calculation of percent mortality. Table 2.5 summarizes the mortality which resulted from radiation in both tests. Animals that survived to D + 70

TABLE 2.5

Mortality and Sacrifice of Surface Exposed Animals During the Surface and Underground Tests

Distance from Ground Zero in Feet	Sheep				Dogs			
	Sacrifice Before D + 10	Sacrifice at D + 10	Died	MST[a] Days	Sacrifice Before D + 10	Sacrifice D + 70 and 75	Died	MST[a] Days
2500[b]	2	0	1	24	3	1	0	-
5000[b]	0	0	0	-	1	0	0	-
8000[b]	0	0	0	-	1	0	0	-
Total	2	0	1		5	1	0	
2500[c]	2	0	4	5	3	0	4	5.5
5000[c]	1	1	3	3.3	2	2	3	7.4
8000[c]	3	1	1	13	3	1	2	8.5
Total	6	2	8		8	3	9	

a. Mean Survival Time in Days of Animals Which Died of Radiation Injury.
b. Surface Test.
c. Underground Test.

are considered as survivors. Only one animal (ewe No. 17) died following exposure during the surface test, while 8 ewes and 9 dogs died of radiation injury following the underground test. Radiation deaths in this test were more numerous among the animals exposed at 2500 feet than at 5000 or 8000 feet because of the high gamma dosages. Similarly mean time to death was somewhat less in the animals exposed at 2500 feet than in those exposed at 5000 and 8000 feet. Nine of 12 surface exposed dogs had died by D + 10 while 8 of 10 ewes had died by D + 13. No foxhole exposed animals died of radiation injury. All of the animals that died following exposure presented terminal symptoms characteristic of radiation injury. No evidence of blast or thermal burn injury appeared in any of the animals autopsied. At the time of sacrifice of ewe No. 7 (D + 70) lesions were found on the skin between the ears. Since this injury had not been observed prior to D + 40 or 50 days, the injury was considered to have resulted from local irradiation produced by an accumulation of fission products which had been trapped on the skin. At D + 70 a survey meter (G-M type) indicated activity of the order of 11 mr/hr at the site of the injury while at the same time a dose rate of 0.5 mr/hr was measured near the animal's hindquarters. Figure 2.1 illustrates the characteristic appearance of the ewes just prior to their death from radiation injury. Both sheep and dogs refused food shortly after exposure and diarrhea appeared by D + 2 in nearly all cases in which the total dosage had been greater than 100 r.

Tables 2.6 and 2.7 present data showing weight changes in exposed dogs and sheep following the underground test. Percentage weight loss in surface exposed animals tended to be greater with higher total body doses, and the dogs generally suffered a greater percent weight loss than the sheep. Foxhole exposed animals showed weight gains or only negligible losses. Neither food nor water were provided the animals during exposure, and although animals were not weighed immediately after their exposure, only small weight differences occurred in the early sacrificed animals. It is assumed, therefore, that the exposure and deprivation were associated with unimportant weight changes.

2.2 EVALUATION OF INTERNAL HAZARD RESULTING FROM EXPOSURE DURING THE SURFACE AND UNDERGROUND DETONATION

2.2.1 Estimation of Internal Radioactivity Following the Surface Test

Activity was so low in all of the tissues studied from all animals sacrificed, irrespective of their location during the contaminating exposure, that no counting data are considered statistically significant. Table 2.8 summarizes the data obtained and the values given are corrected for decay to the sacrifice time for each animal.

Several assumptions were made in order to calculate total

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TABLE 2.6

Weight Changes in Dogs Exposed in the Underground Test

Group[a]	Dog No.	Wt. in Kg. on Day Exposed	Wt. in Kg. at Day of Radiation Death	Wt. in Kg. at Day of Sacrifice	Day of Death	Day of Sacrifice	Gain or Loss, Kg.	% Change in Wt.	External Dose in r[b]
1	16	16.32	12.24		D + 8		-4.08	-25	(360)
	11	15.19	13.15		D + 13		-2.04	-13	(360)
	17	7.25		6.57		D + 2	-0.68	- 9.5	(360)
	22	7.25		5.89		D + 4	-1.36	-18	33
	4	14.05		13.5		D + 9	-0.55	- 3	292
	30	9.97				D + 70			
2	10	12.01	9.75		D + 4		-2.26	-18.8	(1500)
	2	10.9	7.9		D + 8		-3	-27.5	(1500)
	20	12.92	9.52		D + 10		-3.4	-26.3	(1500)
	15	12.92		11.79		D + 4	-1.13	- 8.7	285
	8	9.29		9.07		D + 9	-0.22	- 2	335
	24	8.16		7.93		D + 70	-0.23	- 2.8	73
	28	11.56		12.25		D + 75	+0.69	+ 5.9	10
3	27	11.56		10.2		H + 32	-1.36	-11.7	
4	31	11.32	8.16		D + 4		-3.16	-27.9	1800
	3	9.06	7.25		D + 4		-1.81	-20	2960
	9	9.07	7.25		D + 4		-1.82	-21	2525
	1	12.2	9.5		D + 10		-2.7	-22.1	(3100)
	7	8.16				H + 10			1325
	5	8.16		6.80		D + 2	-1.36	-17	(3100)
	13	12.92		10.88		D + 4	-2.04	-15.8	2740
5	32	5.89		7.9		D + 75	+2.19	+37.2	
	19	7.25		6.8		D + 4	-0.45	- 6.2	

a. Groups designated as follows:
   1. 8000 foot, surface exposed
   2. 5000 foot, surface exposed
   3. 5000 foot, foxhole exposed
   4. 2500 foot, surface exposed
   5. 2500 foot, foxhole exposed

b. Dose given in parentheses is estimated.

TABLE 2.7

Weight Changes in Ewes Exposed in the Underground Test

Groups[a]	Ewe No.	Wt. in Kg. on Day Exposed	Wt. in Kg. at Day of Radiation Death	Wt. in Kg. at Day of Sacrifice	Day of Death	Day of Sacrifice	Gain or Loss, Kg.	% Change in Wt.	External Dose in r[c]
1	11	46.7	Missing		D + 13				(360)
	12	59.8		52.1		D + 2	- 7.7	-13	(360)
	10[b]	45.3		40		D + 4	- 5.3	-11.7	(70)
	23[b]	49.6		53.9		D + 9	+ 4.3	+ 8	4
	21[b]	36.7		47.6		D + 75	+10.9	+23	15
2	9	49.4	44		D + 3		- 5.4	-11	(1500)
	8	45.3	Missing		D + 4				285
	6[b]	45.3	40.3		D + 4		- 5	-11	253
	2[b]	40.3		38.5		D + 9	- 1.8	- 4.4	7
	7[b]	59.8		65.3		D + 70	+ 5.5	+ 8.2	350
3	19[b]	44.9		52.6		H + 21	+ 7.7	+17.1	
	22[b]	53.5		74.8		D + 75	+21.3	+40	
4	4[b]	44.4		42.2		D + 2	- 2.2	- 5	2425
	3	39	29		D + 4		-10	-25.6	2425
	5	56.2	45.8		D + 6		- 8.4	-14.9	2075
	24	60.2	51.7		D + 8		- 8.5	-14.1	1800
	1[b]	42.2		42.2		H + 14	-	-	1400
	13	53.5		49.4		D + 4	- 4.1	- 7.6	1310
5	20[b]	44.4		39		D + 4	- 5.4	-12.1	
	25	50.7		63		D + 75	+12.3	+21.5	

a. Groups designated as follows:
   1. 8000 foot, surface exposed
   2. 5000 foot, surface exposed
   3. 5000 foot, foxhole exposed
   4. 2500 foot, surface exposed
   5. 2500 foot, foxhole exposed

b. Pregnant an estimated 2-3 months at the time of exposure.

c. Dose given in parentheses is estimated.

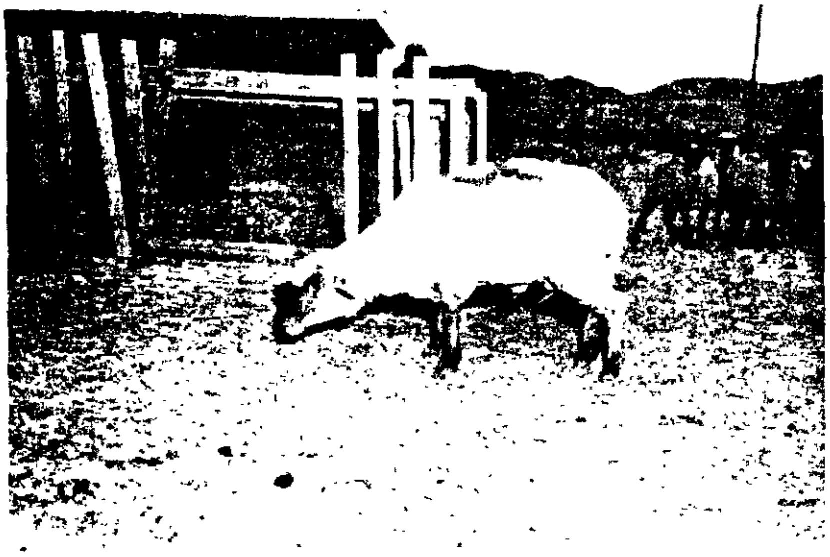

Figure 2.1. Ewe No. 8 at D + 3, One Day Prior to Radiation Death Following a Dose of 285 r

radioactive contamination which was present in the animals at the time of their sacrifice. None of the preparations contained sufficient activity to enable decay curves to be made. It was necessary to assume that the distribution of fission products inhaled and ingested corresponded with that which was found for crater and lip earth samples. This assumption seems reasonable in view of the fact that it was found that highly active samples of gut contents and certain tissues taken from animals exposed in the underground test gave decay curves whose slopes fitted reasonably well when compared to similar portions of earth sample decay curves.

Data on tissue samples given in Table 2.8 are subject to a large error because the counting rate was low for all samples and 10 minute counts only were obtained. It is considered worthwhile, however, to present the data with the foregoing reservations to enable a comparison to be made between the surface and underground types of contaminating detonations with respect to their relative internal hazard.

Radioactive contamination for the whole animal was estimated from the counts made upon small samples of lung, kidney, liver, spleen, and blood by multiplying the total weight of the animal by the mean for the samples counted. This procedure presupposes that the musculature of each animal contained an amount of radioactive contamination which was equal to the mean for those organs which were

TABLE 2.8

Estimation of Total Internal Contamination at Sacrifice Time in Animals Exposed at the Surface and in Foxholes During the Surface Test

Group[a]	Animal[b] No.	Time of Sacrifice	Wt. in Gms.	Tissue	d/min/gm	d/min[c]	μc at time of Sacrifice	μc in % of total at Sacrifice Time
1	Dog 29	H+28	7,710	Total body	15.3	1.2×10^5	0.054	100
			72	Lung	35.4	2.5×10^3	0.0012	4.0
				Gut cont.[d]	15.7			
2	Dog 12	H+28	12,240	Total body	28.64	3.5×10^5	0.16	
			85	Lung	0			
				Gut cont.	57.8			
3	Dog 26	H+16	9,520	Total body	23.7	2.3×10^5	0.10	100
			82	Lung	26.3	2.3×10^3	0.0010	1
4	Dog 23	H+ 8	11,330	Total body	202.98	2.3×10^6	1.03	100
			105	Lung	324.4	3.4×10^4	0.0153	1.5
				Gut cont.	36.1			
	Dog 18	D+ 4	88	Lung	44.1	3.8×10^2	0.0002	
				Gut cont.	-0			
	Ewe 18	D+ 4	67,100	Total body	30.3	2.03×10^6	0.915	100
			659	Lung	34.8	2.3×10^4	0.010	1.1
				Gut cont.	22.5			

a. Groups designated as follows:
   1. 8000 foot, surface exposed
   2. 5000 foot, surface exposed
   3. 5000 foot, foxhole exposed
   4. 2500 foot, surface exposed

b. See Tables 2.1 and 2.2 for location of animal stations.

c. Total body weight X mean d/min/gm for all tissues counted.

d. Mean values per gram of contents of stomach, small intestine and large intestine.

[redacted]

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TABLE 2.8 (Continued)

Estimation of Total Internal Contamination at Sacrifice Time in Animals Exposed at the Surface and in Foxholes During the Surface Test

Group[a]	Animal[b] No.	Time of Sacrifice	Wt. in Gms.	Tissue	d/min/gm	d/min[c]	µc at time of Sacrifice	µc in % of total at Sacrifice Time
5	Ewe 15	H+12	41,500	Total body	61.34	2.5×10^6	1.120	100
			625	Lung	93.50	5.84×10^4	0.02	1.8
				Gut cont.[d]	427			
	Dog 21	H+15	12,670	Total body	35.2	4.45×10^5	0.200	100
			131	Lung	45.1	5.9×10^3	0.0026	1.4
	Ewe 16	H+ 9	33,300	Total body	146.1	4.86×10^6	2.18	100
			557	Lung	163.1	9.08×10^4	0.041	1.8
				Gut cont.	177.1			

a. Groups designated as follows:
   5. 2500 foot, foxhole exposed
b. See Tables 2.1 and 2.2 for location of animal stations.
c. Total body weight X mean d/min/gm for all tissues counted.
d. Mean values per gram of contents of stomach, small intestine and large intestine.

studied. The contribution of the gut contents to the total internal dose cannot be assessed reliably. Animals which were sacrificed on or before H + 28 hours had fasted for about 36 hours and as a result had only small amounts of fluid in the gut while the animals which were sacrificed after H + 28 had been feeding and passing feces thereby diluting and removing activity.

For dogs exposed at the surface at 2500, 5000 and 8000 feet the calculated amounts of total body radioactivity were 0.998, 0.14, and 0.054 µc respectively as shown in Table 2.8. Sacrifice times for these animals were from H + 8 to H + 28 hours, the measured values having been corrected for decay to the sacrifice time of each animal. By D + 4 the activities of the tissues in dog No. 18 had decayed to undetectable amounts. Total activity in two dogs which had been exposed in foxholes at 2500 and 5000 feet were calculated to be 0.184 and 0.092 µc respectively. A lower total body internal radioactive contamination occurred at the more distant foxhole exposure. Total internal contamination for a surface exposed dog (No. 23) was about

5 times that found for a foxhole exposed dog (No. 21) although the stations were within 350 feet of each other. Within the limits of accuracy of the measurements these data indicate that the foxhole position afforded a slight protection from contamination due to air-borne radioactive particulate material. This protective effect was less marked at 5000 feet where the total activity in surface (0.14 μc) and foxhole (0.092 μc) exposed dogs No. 12 and 26 respectively are comparable.

No surface exposed sheep were sacrificed before D + 4. Total body activity at D + 4 for ewe No. 18 was 0.915 μc, less than 0.005 μc per gram of body weight. Contamination found in two foxhole exposed ewes, No. 15 and No. 16 (2500 feet) was considerably higher than that found in dog No. 21 which was exposed in an adjacent foxhole. Furthermore, it may be noted that the mean gut activity of these two ewes was higher than that found for any of the animals sacrificed before H + 24. This discrepancy is consistent with the fact that the ewes, in handling larger volumes of air would obtain larger amounts of dust for a given exposure time.

A large fraction of the inhaled dust is not retained in the lungs but is removed from the bronchi to the trachea by means of ciliary activity. When the inhaled particles which have precipitated on the moist membranes of the upper respiratory tract are moved into the pharynx they are swallowed and thus enter into the digestive tract. An indeterminate amount of this material reaches the circulation through the gut walls and another fraction of it is eliminated in the feces. Gut contamination is also derived from dust on the hairs about the mouths of the animals. Dogs are mouth breathers more or less of the time and also lick themselves about the face and body frequently. Sheep on the other hand are primarily nose breathers and therefore probably derived the bulk of their gut contamination secondarily from the lungs.

From the comparison of the area of principal fall-out as determined from independent measurements it is clear that the plan of layout of animal stations was such that few of the animals were subjected to the maximum contaminating exposure. This largely accounts for the low activity found in the tissues studied and it is possible only to speculate upon the amount of radioactivity which might have been taken up had the animals been exposed at positions of maximum dust concentration during the surface test.

2.2.2 Summary - Surface Test

1. Total body internal radioactive β contamination was calculated to be less than 1 μc in surface exposed dogs sacrificed before H + 28. A foxhole exposed dog sacrificed within a comparable time had less than 0.2 μc of radioactivity.

2. By D + 4 the counts in tissues were reduced below detectable limits.

3. Amounts of radioactivity calculated for individual animals decreased with distance from ground zero.

4. Neither bone nor soft tissue samples from animals sacrificed at D + 70 contained detectable radioactivity.

2.3 DETERMINATION OF INTERNAL RADIOACTIVITY AND DOSAGE IN TEST ANIMALS FOLLOWING THE UNDERGROUND TEST

2.3.1 Limitation of Field Methods and Measurements

Larger amounts of contamination were present in many tissues obtained from animals sacrificed after exposure during this test than in the surface test. It was therefore possible to estimate with somewhat greater accuracy the total internal activity which resulted from the combined inhalation and ingestion of radioactive dust. Several assumptions have been made in converting experimental data to total activity and total internal dosage and these assumptions will be considered at appropriate places in the discussion of the results. It is unlikely that the order of magnitude of the results would have been altered even with shorter sacrifice intervals and larger numbers of animal stations. Physiological variation between test animals as well as variability in the degree of contaminating exposure accounts for some of the variability in the data about to be presented. The concentration of dust during exposure was controlled only by placing the exposure stations along the arcs indicated in Tables 2.3 and 2.4. No precautions could be taken to insure uniformity in the amount of contaminating exposure. The exposed animals were fasting at the time of exposure and were confined under conditions which might be expected to alter normal respiratory rates. Environmental temperature was low (Appendix C) at the time of exposure and probably resulted in shivering among some of the animals. Shivering may have altered the circulatory rate and in turn effected in some way the rate at which materials were carried through the gut and viscera. Since the effects of internal gamma emitters would be negligible gamma activity was not determined in tissue samples.

Recovery time for some animals was H + 6 hours while the remainder were recovered at H + 24 hours. The extended period of time and the consequent longer fast together with increased total body dosage represent variables of unknown magnitude in respect to internal distribution of activity.

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2.3.2 Total Amounts of Radioactivity and Internal Dosage Due to β Activity

Total activities at sacrifice time were calculated from counts obtained on weighed tissue samples prepared as described in Appendix B. Disintegration rate for each organ selected was found as follows:

$$(d/gm/min)_{organ} = (c/min/gm)(\text{geometry correction})(\text{decay correction})$$

An average value for the disintegration rate per gram for the total soft tissues of each animal was determined from the sum of the organ rates.[1] Total body disintegration rate was then found after multiplying the average value for each animal by the total weight of soft tissues. From this value total microcuries was obtained:

$$\text{Total } \mu c = \frac{\text{Total } d/gm/min}{2.22 \times 10^6}(\text{body weight})$$

Substitution of (organ weight) and (total $d/gm/min)_{organ}$ in the preceding equation gives the total microcuries for a specific organ at sacrifice time.

Figure 2.2 gives the disintegration rate for soft tissues of a few of the animals at the time of their sacrifice. Inspection of the distribution of the experimental points in the figure shows the large amount of variation in the data. The area under a linear plot of the curve shown in Figure 2.2 represents the total disintegrations for an average test animal. Integrated internal dose for the inhaled and ingested mixture was obtained from the experimental points by averaging their extropolated values at H + 10 hours and drawing the decay curve for the earth sample β components through this average. Roentgen dosage was calculated as follows:

$$\text{Integrated internal dose, rep}^2 = \frac{(\text{Total } d/gm/min)(0.7\text{Mev})(1.6 \times 10^{-6})}{83 \text{ ergs}}$$

and the internal dosage for individual animals was taken as proportional to the dose calculated for the average animal and assumes survival to H + 1000 hours. A similar procedure was used in obtaining roentgen dosage to lungs of test animals. Table 2.9 compares internal dose and lung dose due to β activity with external gamma dose. Total internal dose for dogs ranged from 0.10 to 0.43 rep and from 0.05 to

1. For a given test animal counts on samples of lung, spleen, liver, kidney and blood were required in order to compute total body activity. Blood was taken as 7.2% of the body weight.
2. R.E. Lapp, and H.L. Andrews, Nuclear Radiation Physics, Prentice Hall Co; 1948, p. 435.

0.31 rep for sheep. Roentgen dose to lung tissue was higher than that for other soft tissues and for dogs had a range of 0.25 to 7.03 rep

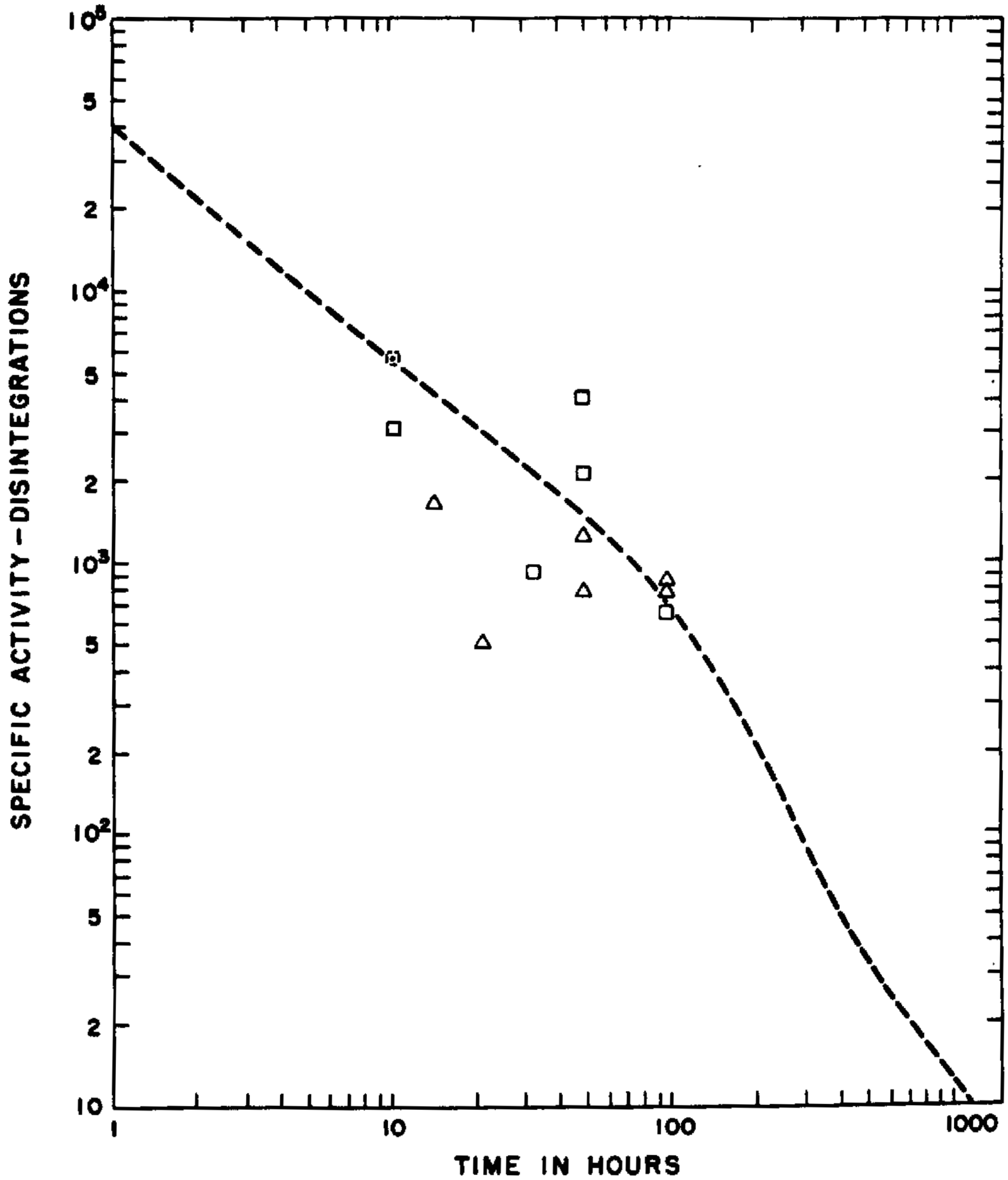

Figure 2.2. Disintegrations Per Gram Per Minute in Soft Tissues of Dogs □ and Sheep △ at the Time of Their Sacrifice Compared with the Physical Decay of the β Components in the Earth Sample (- - -)

TABLE 2.9

Internal Dose and Lung Dose Due to β Activity Compared to External Dose in Animals Exposed During the Underground Test

Animal No.	Time of Sacrifice Hours	Integrated Dose rep[a]	Lungs Integrated Dose rep[a]	External Dose r[b]
Dogs				
7	10	0.18	2.37	1325
27	32	0.10	0.41	12
5	48	0.43	3.14	(3100)
17	48	0.41	7.03	(360)
13	96	0.19	1.96	2740
Sheep				
1	14	0.10	0.47	1400
19	21	0.05	0.10	11
4	48	0.22	0.99	2425
12	48	0.13	4.69	(360)
20	96	0.31	8.83	133
10	96	0.25	0.19	(360)

a. Values given for test animals are obtained from calculations based on the area under a linear plot of the curve shown in Figure 2.2 and assume survival to H + 1000 hours.

b. External dose in parentheses is estimated.

compared to 0.19 to 8.83 rep for sheep. No correlation could be found between external gamma dose and internal dose among the surface exposed animals. Dog No. 27 and ewe No. 19 were foxhole exposed animals and their internal dosage as well as lung dosage were low. On the other hand ewe No. 20 was also exposed in a foxhole position and her total internal dose as well as lung dose were the highest for the series.

Total body activity in microcuries at sacrifice time was determined when experimental data were sufficiently complete. Tables 2.10 and 2.11 summarize the data for total body and total lung activity in the test animals. Activity in the soft tissue was reduced below detectable limits in animals sacrificed after D + 9 days. Total amounts of radioactive materials (as corrected to sacrifice time) taken up were higher on the average in the ewes than in the dogs. The range for the ewes was from 2.22 to 31.12 μc and from 3.24 to 11.70 μc in the dogs. Similarly the total lung uptake was greater in the ewes, 0.05 to 7.44

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TABLE 2.10

Radioactivity in Soft Tissues and in Lungs at the Time of Sacrifice in Dogs Exposed During the Underground Test

Group[a]	Dog No.	Sacrifice Time	Total Tissues µc	Total Tissues µc/gm	Integrated Dose rep[b]	Lung µc	Lung Integrated Dose rep[b]
1	17	D + 2	11.70	0.0016	0.41	0.730	7.03
	22	D + 4				0.007	0.25
	4	D + 9				0.036	0.83
	30	D + 70	0				
2	15	D + 4				0.036	0.51
	8	D + 9				0.008	0.69
	24	D + 70	0				
	28	D + 75	0				
3	27	H + 32	4.19	0.0003	0.10	0.080	0.41
4	7	H + 10	11.60	0.0014	0.18	1.160	2.37
	5	D + 2	6.43	0.0007	0.43	0.385	3.14
	13	D + 4	3.24	0.0002	0.19	0.235	1.96
5	19	D + 4				0.217	3.83
	32	D + 70	0				

a. Groups designated as follows:
   1. 8000 foot, surface
   2. 5000 foot, surface
   3. 5000 foot, foxhole
   4. 2500 foot, surface
   5. 2500 foot, foxhole

b. Determined as explained in text, 2.3.2.

µc, than in the dogs, 0.007 to 1.16 µc. This result is in agreement with the relatively larger lungs and higher respiratory rate of sheep.

Specific activities at sacrifice time of all of the tissues examined may be compared in the data given in Tables 2.12 and 2.13. Of all the soft tissues examined lungs had the highest specific activity. Lung specific activity in the dogs was higher than in sheep at any given time of sacrifice with the exception of the two animals- ewe No. 20 and dog No. 19, both of which were sacrificed at D + 4 after exposure in foxholes. Specific activity in the lungs and other organs

TABLE 2.11

Radioactivity in Soft Tissues and in Lungs at the Time of Sacrifice in Ewes Exposed During the Underground Test

Group[a]	Ewe No.	Sacrifice Time	Total Tissues		Integrated Dose rep[b]	Lung	
			μc	μc/gm		μc	Integrated Dose rep[b]
1	12	D + 2	18.75	0.0003	0.13	3.43	4.69
	10	D + 4	2.22	0.0001	0.25	0.05	0.19
2	19	H + 21	11.80	0.0002	0.05	0.11	0.10
3	1	H + 14	31.12	0.0007	0.10	0.92	0.47
	4	D + 2	23.79	0.0006	0.22	0.52	0.99
	13	D + 4				0.15	0.47
4	20	D + 4	14.95	0.0004	0.31	7.44	8.83

a. Groups designated as follows:
   1. 8000 foot, surface
   2. 5000 foot, foxhole
   3. 2500 foot, surface
   4. 2500 foot, foxhole

b. Determined as explained in text, 2.3.2.

was highest in the animals which were sacrificed early and diminished rapidly in animals sacrificed later. Variation in the data was such as to prevent making a reliable estimate of the retention time for the radioactive mixture in the organs.

Pulmonary lymph nodes had lower specific activities than might have been anticipated in view of their function and considering the fact that histological preparations of the lymph nodes contained accumulations of dust particles. Specific activities of kidney, spleen and liver tissues were nearly similar indicating a generalized distribution of the radioactivity among these organs. Blood specific activity was less than spleen or kidney tissues (except for ewe No. 1) showing that in passing through these organs some of its radioactive burden was given up. Urine generally had a higher specific activity than the blood and frequently higher than the kidney from which it was derived.

Specific activity of gut contents in dogs, shown in Table 2.14 was 5 to 10 times higher than lung tissue activity in the

TABLE 2.12

Specific Activities in $\mu c/gm$ at Sacrifice Time of Various Organs from Dogs Exposed During the Underground Test

Group[a]	Dog No.	Sacrifice Time	Lung	Lymph[b] Node	Kidney	Spleen	Liver	Blood	Urine[c]
1	17	D+ 2	0.0110	0.0049	0.014	0.0018	0.0016	0.0003	0.0065
	22	D+ 4	0.0001	0	0				
	4	D+ 9	0.0004	0.0002					
	30	D+70		0		0	0		
2	15	D+ 4	0.0003	+	+				
	8	D+ 9	0.0001	+					+
	24	D+70	0	0		0	0		0
	28	D+75	0	0		0	0		0
3	27	H+32	0.0008	0.0003	0.0002	0.0004	0.0003	+	0.0017
4	7	H+10	0.0141	0.0003	0.0012	0.0009	0.0014	0.0002	0.0001
	5	D+ 2	0.0051		0.0018	0.0013	0.0009	+	0.0002
	13	D+ 4	0.0025	0.0019		0.0005		0.0002	0.0005
5	19	D+ 4	0.0033	0.0005		0.0003		+	0.0001
	32	D+75	0	0		0			0

Note: Plus indicates that planchet counts were just detectable; 0 indicates no detectable activity; where no figure is given, the determination is lacking.

a. Groups designated as follows:
   1. 8000 foot, surface
   2. 5000 foot, surface
   3. 5000 foot, foxhole
   4. 2500 foot, surface
   5. 2500 foot, foxhole

b. Pulmonary lymph nodes.

c. 1 ml quantities of urine were sampled.

TABLE 2.13

Specific Activities in μc/gm at Sacrifice Time of Various Organs from Ewes Exposed During the Underground Test

Group[a]	Ewe No.	Sacrifice Time	Lung	Lymph[b] Node	Kidney	Spleen	Liver	Blood	Urine[c]
1	12	D+ 2	0.0072	0.0006	0.0005	0.0002	0.0006	0.0001	
	10	D+ 4	0.0001	0	0.0001		+	0	+
	23	D+ 9	0	0	+				
	21	D+75	0	0		0	0		0
2	6	D+ 4	0.0001	0	0			0	0.0002
	2	D+ 9	+	0	0				
	7	D+70		0		0			0
3	19	H+21	0.0002			+	+	0.0005	0.0049
	22	D+75	0	0		0	0		0
4	1	H+14	0.0019		0.0001	0.0013	0.0004	0.0014	
	4	D+ 2	0.0015		0.0003	0.0020	0.0007	0.0002	
	13	D+ 4	0.0003	0.0002		0		0	0.0003
5	20	D+ 4	0.015	0.0003		0.0003		0	0.0004
	25	D+75	0			0	0		0

Note: Plus indicates that planchet counts were just detectable; 0 indicates no detectable activity; where no figure is given, the determination is lacking.

a. Groups designated as follows:
   1. 8000 foot, surface
   2. 5000 foot, surface
   3. 5000 foot, foxhole
   4. 2500 foot, surface
   5. 2500 foot, foxhole
b. Pulmonary lymph nodes.
c. 1 ml quantities of urine were sampled.

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TABLE 2.14

Specific Activity in μc/gm of
Gut Contents of Dogs Exposed During the Underground Test

Group[a]	Dog No.	Sacrifice Time	Stomach	Small Intestine	Feces[b]
1	17	D + 2	0.020	0.106	0.066
	4	D + 9		0.002	
2	27	H + 32	0.003	0.010	0.004
3	7	H + 10	0.140		2.962
	5	D + 2		0.087	0.067

TABLE 2.15

Specific Activity in μc/gm of
Gut Contents of Ewes Exposed During the Underground Test

Group[a]	Ewe No.	Sacrifice Time	Stomach	Small Intestine	Feces[b]
1	12	D + 2		0.0059	0.0032
	10	D + 4	0.0076	0.0002	
	23	D + 9		0.0001	
2a	6	D + 4		0.0013	
3a	19	H + 21	0.0032	0.0017	
4	1	H + 14	0.0019		0.0012
	4	D + 2	0.0003	0.0003	0.0004

a. Groups designated as follows:
   1. 8000 foot, surface
   2. 5000 foot, foxhole
   2a. 5000 foot, surface
   3. 2500 foot, surface
   3a. 5000 foot, foxhole
   4. 2500 foot, surface

b. Feces were taken from the colon during autopsy.

corresponding animal. This greater amount of activity may partly be due to the fact that the dogs tended to lick themselves and thus ingest radioactive materials collected by the pelt during exposure. Table 2.15 shows that sheep gut contents had only slightly greater specific activity than did the lung tissue of the corresponding animal. No correlation between distance from ground zero and gut activity was evident from the data obtained, nor was there evidence that gut contents of foxhole exposed animals had lower specific activities than surface exposed animals.

The contribution of the contamination in the gut contents to the total internal dose was not evaluated because of the difficulties inherent in the field operations. Animals which had been sacrificed at early times after the shot had fasted for about 36 hours and consequently had only small amounts of fluid in the gut. Animals sacrificed later had taken food and passed feces so that it was felt that estimated quantities of radioactivity would not be realistic.

2.3.3 Comparison of Decay of Contaminating Materials with Earth Sample β Decay[1]

Quantitative and qualitative radiochemical analysis of the radioactive components in the tissues of sacrificed animals was impractical because of the minute amounts of activity present. It was therefore decided to assume identity of internal contamination with earth sample activity. Evidence that fractionation of the inhaled and ingested materials had occurred by the time of sacrifice is shown in Figures 2.3, 2.4 and 2.5. Two animals, dog No. 7 and ewe No. 1 were found to have acquired sufficient activity to permit decay curves to be made of the activity in some tissues. Figure 2.3 shows β decay curves for gut contents and for blood, kidney, lung and spleen of dog No. 7 and allows a comparison of the individual slopes with that found for earth samples. Contamination in stomach contents and lung tissue decays along a slope which appears nearly parallel with the earth sample β decay. Contents of the large intestine have a somewhat steeper slope during the period studied. This lack of correspondence indicates that chemical fractionation of the radioactive materials had taken place during the passage along the gut and is evidence that at least some of the activity measured in the tissues must have been derived from gut contents. The blood and kidney slopes, -1.41 and -1.46 respectively, are nearly linear on a log-log plot and therefore different from the lung and gut contents slopes. On the other hand the spleen contamination decays at a rate which is similar to that

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1. Crater and lip sample measurements and radiochemical analyses were provided by Dr. Charles R. Maxwell and Capt. Saul J. Abraham of Project 2.6 and the authors wish to express their appreciation for these data.

found for the earth samples.

Figure 2.4 gives decay curves of the contamination found in some of the tissues and gut contents of ewe No. 1. In this case the similarity between decay curves of stomach contents and the earth sample is less striking than that shown in Figure 2.3 for the dog. Decay slope for the blood is -1.48 compared to -1.24 for spleen.

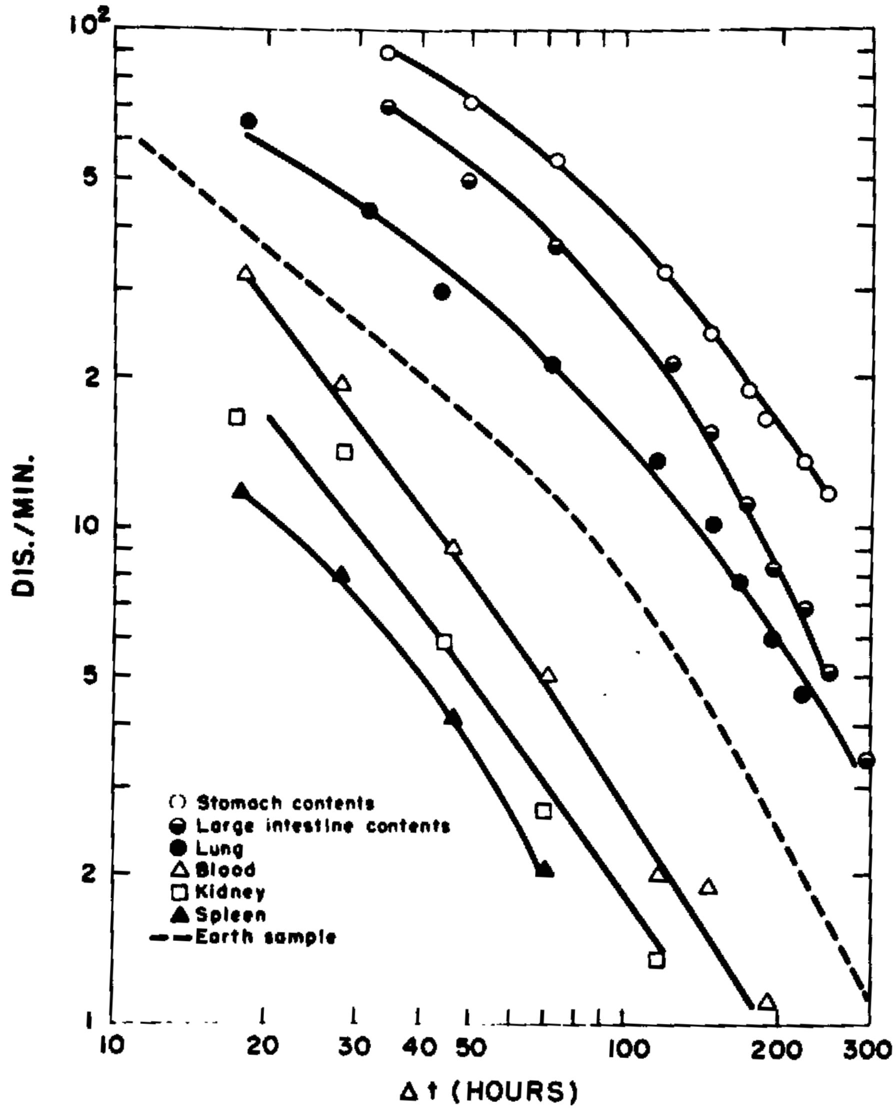

Figure 2.3. Comparison of the β Decay Curves of the Activity in Tissues from Dog No. 7 With Those of Its Gut Contents and Earth Sample

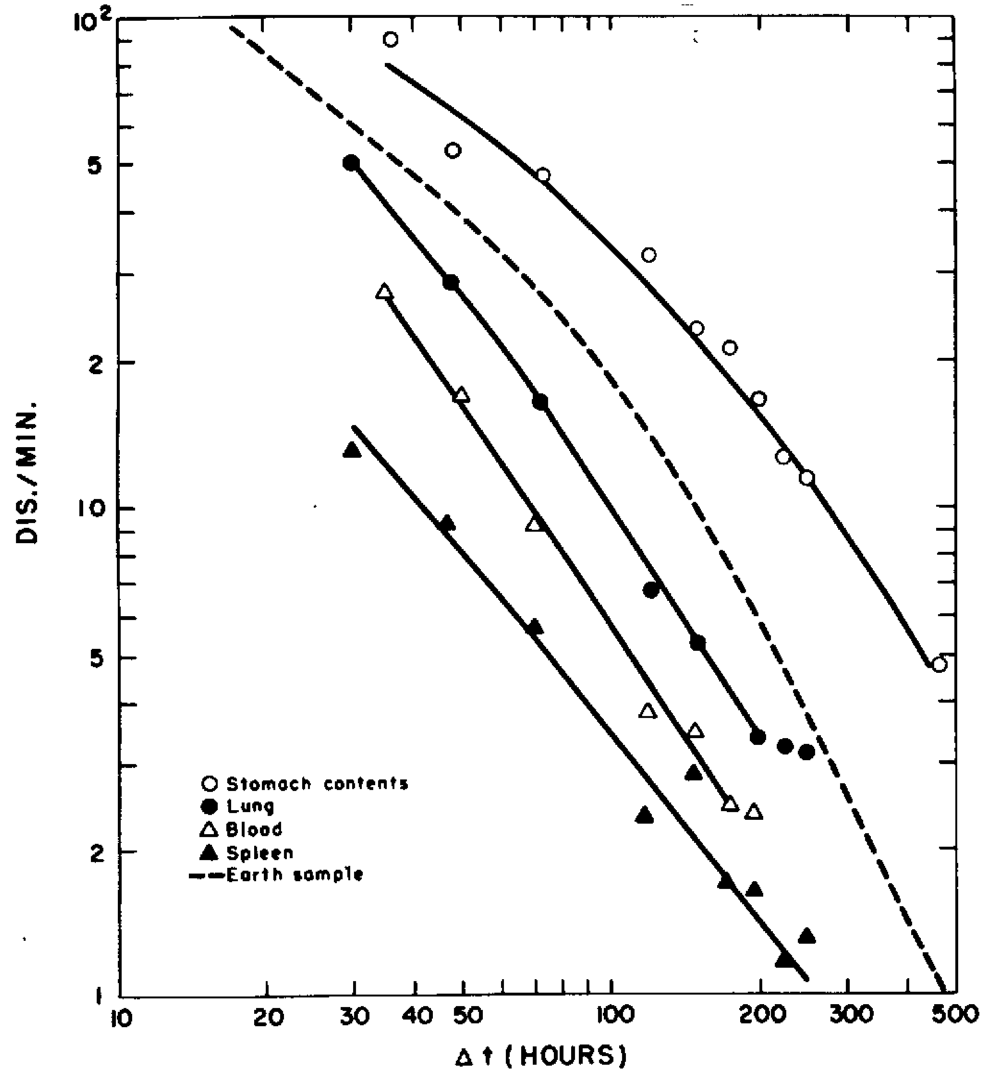

Figure 2.4. Comparison of the β Decay Curves of Activity in Tissues of Ewe No. 1 With Those of Its Gut Contents and Earth Sample

Decay of lung activity is not linear on a log-log plot and corresponds roughly to the earth sample and stomach contents decay curves.

A third illustration of the fractionation which has occurred is shown in Figure 2.5 which compares the earth sample decay with stomach contents, blood, amniotic fluid, placenta and fetal liver. The amniotic fluid β decay slope is -1.27 compared with a slope of

-1.48 for the blood of the same animal. Placental tissue decay parallels stomach contents. Too few points could be obtained for fetal liver to describe a slope accurately, however, if the points be taken to represent a straight line then the slope of the line is -1.26 and therefore similar to that found for the amniotic fluid. This latter assumption implies that chemical fractionation is complete by the time the activity has reached the amniotic fluid. The maternal tissue, represented by the placental curve in Figure 2.5 obviously contained a different mixture of radioactive materials than the fetal liver or amniotic fluid. The residue of activity to which the developing fetus was subjected was therefore different from that which was contained in the closely associated maternal tissue. Furthermore the specific activity was lower in fetal tissues, suggesting that by successive dilution and fractionation in maternal tissues the fetus was subjected to a lower total dose than might have been expected with a completely uniform distribution of activity.

Specific identification of the contamination detected in the tissues could not be undertaken and it has been shown that the internal distribution of the inhaled and ingested radioactive mixture was not uniform quantitatively or qualitatively. It was found possible to make β absorption curves (from H + 148 hours) for the stomach contents of dog No. 7 and for the urine from sheep No. 19. Analysis of these curves indicates that the energy spectra for the activity in the two samples were different thus emphasizing that in its passage through the tissues the inhaled and ingested mixture is fractionated.

2.3.4 Estimation of Amounts of Activity in Fetal Tissues from Pregnant Ewes Exposed During the Underground Test

Radioactivity in amniotic fluid ranged from 1×10^{-4} to 9×10^{-4} μc per gram and in placental tissue from 1×10^{-4} to 5×10^{-4} μc per gram. In Figure 2.5 it was shown that the composition of the activity in the amniotic fluid was not identical with that in the placenta.

Activity per ml. of amniotic fluid in one instance (ewe No. 1) was 9×10^{-4} μc/gm compared to only 5×10^{-4} μc/gm of placental tissue. Total activity in the amniotic fluid[1] in this case was estimated to be of the order of 0.35 μc or just over 1% of the total μc of activity occurring in the mother. Spleen tissue taken from the fetus in this ewe contained as much activity per gram as did the placenta whereas the liver had 1×10^{-4} μc per gram.

No significant activity was found in any fetal tissue from ewes sacrificed after 48 hours after exposure. Data were not

1. This calculation assumes a total volume of 1500 ml.

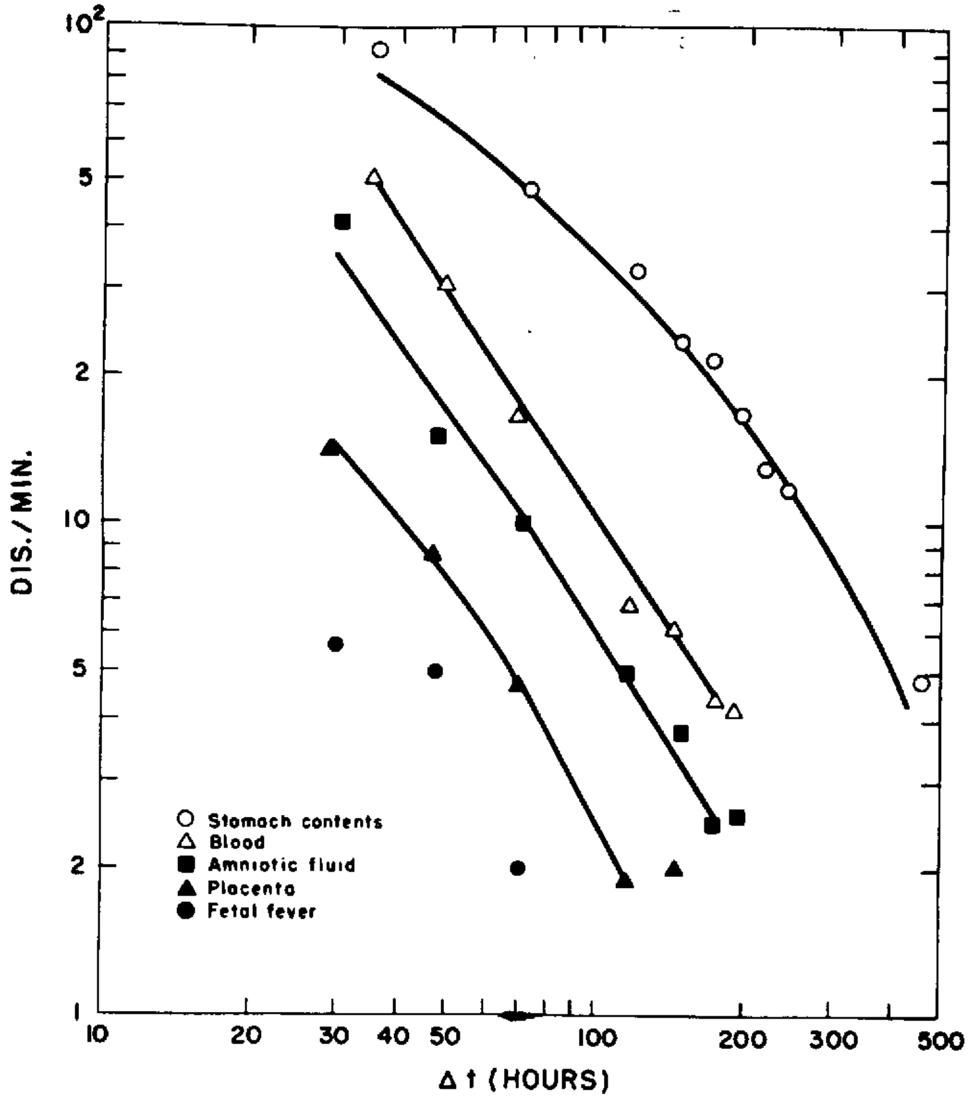

Figure 2.5. Decay Curves of β Activity in Stomach Contents and Blood Compared with Amniotic Fluid, Placenta and Fetal Liver in Ewe No. 1

obtained which would permit a calculation to be made of integrated dose for the developing fetuses. It is estimated from the data available that activity was so low that the dose was below physiological significance. No evidence of radioactivity in fetal bones could be found, thus indicating that neither Ba^{140} nor Sr^{90} passed the placental barrier in detectable amounts.

One ewe (No. 7) gave birth to two normal lambs on D + 69.

External gamma dose to this animal was 350 r, a dose which had been lethal to several ewes as indicated in Table 2.3. Under the conditions of exposure in the underground test some developing sheep fetuses had quantities of radioactivity which were just physically detectable. From the fact that no fetal radioactivity could be detected after H + 48 hours and from the fact that one ewe carried her lambs to normal birth, it is assumed that normal development and parturition could have followed in all the pregnant ewes which would have survived the external dose.

2.3.5 Deposition of Radioactive Material in Bones of Test Animals

Radiochemical analysis of material from the bones of pup C[1] and dog No. 17 strongly indicated that the activity was due to radioactive barium and strontium. The calculated decay curve[2] of Ba^{140} and Sr^{90} compares favorably with experimental determinations of decay of the activity in several bone samples as shown in Figure 2.6. These facts do not exclude the possibility that the bone activity may have been due to additional materials besides these two components. However, the data are taken as evidence that deposition of both Ba^{140} and Sr^{90} had occurred in the bones of some of the dogs. Activity in the bones of the several dogs indicated in Figure 2.6 was qualitatively uniform.

Bone samples were prepared by wet ashing with nitric acid and Table 2.16 presents data showing the specific activity of the bone at the time of their sacrifice or death in the animals exposed to the underground detonation. Roentgen dosage to the bone could not be calculated because of differences in uptake and wide variability among determinations. There is a correlation between bone activity and exposure position during the test. Femurs of most of the dogs exposed at 2500 feet contained appreciable amounts of activity while few of the femurs of dogs exposed at 5000 or 8000 feet contained enough activity to be significant in counting. Femurs of three pups exposed at each of the three distances had the highest specific activity due probably to the greater rate of bone growth in the juveniles. Sheep femurs did not contain sufficient activity for reliable measurement. The nearly complete absence of detectable radioactivity in sheep bones may be due to sampling error if it is assumed that the metabolism of the bone-seeking mixture which was taken up was similar in sheep and dogs. A smaller quantity would have been deposited per gram of bone in the sheep than in the dogs because of the greater total quantity of bone in the sheep. Dilution in this way may have obscured the detection of activity in 0.5 gm. samples of bone even though the total activity was somewhat

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1. Pup C and dog No. 17 were placed together in a cage during exposure at 8000 feet.
2. This calculation assumes an initial ratio of 1 Sr^{90}: 5 Ba^{140}.

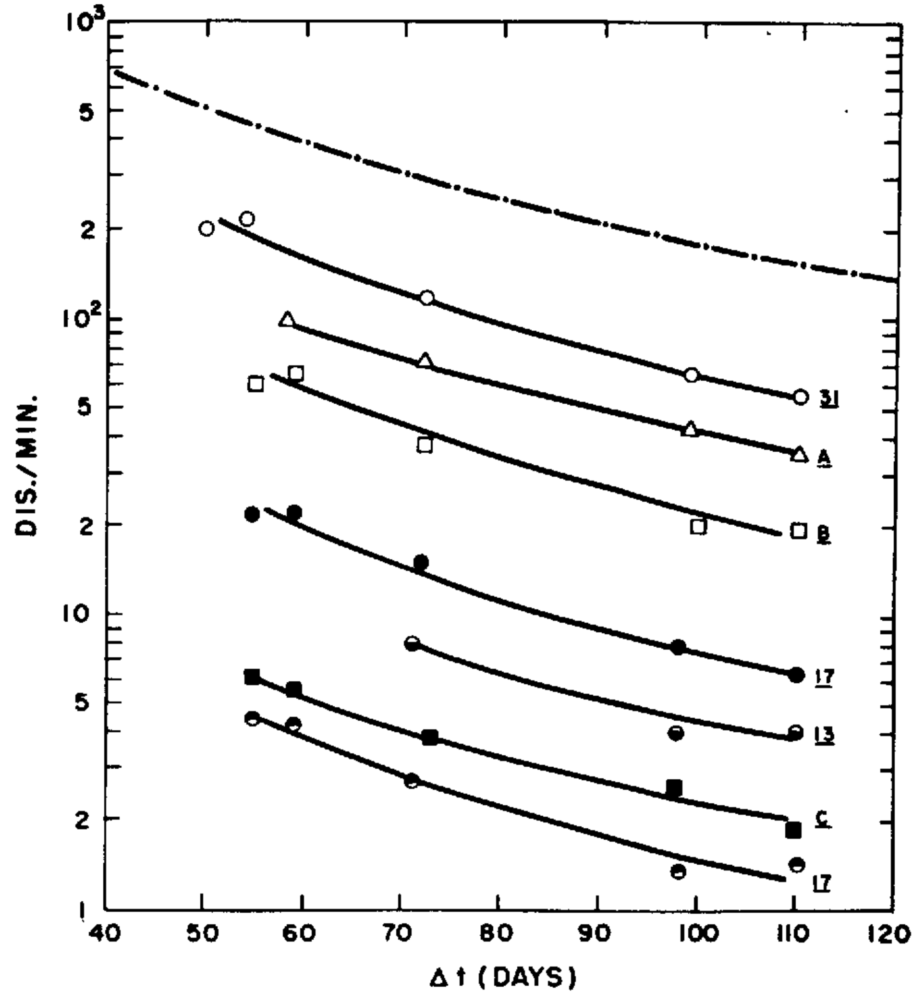


Figure 2.6. Comparison of the Decay of Radioactivity Deposited in the Femurs of Adult Dogs Nos. 31, 16, and 13, and Three Pups, A, B, C, (solid lines) With a Calculated Curve of Ba^{140} and Sr^{90} (broken line). The calculated curve assumes an initial ratio of 1 Sr^{90}: 5 Ba^{140}.

higher in sheep than in dogs.

Figure 2.7 shows the distribution of the activity in the bones of the 3 pups and one adult dog (No. 17). Pup bones show deposition of activity in epiphysial cartilage and an almost equally heavy deposition in the spongiosa and shaft. The portion of the head of the femur of the adult dog shows a faint shadow along the shaft and the contour of the proximal end of the bone is just visible.

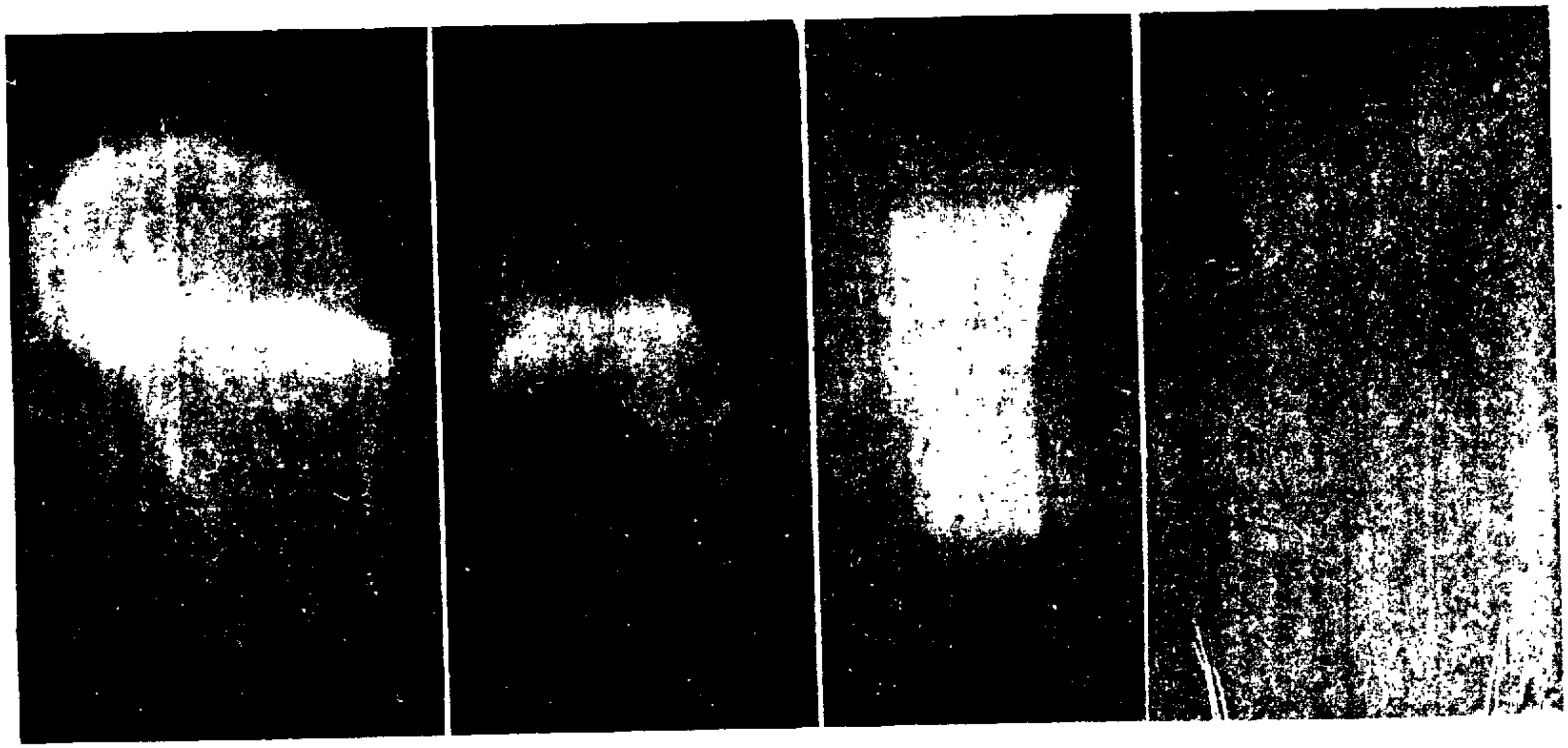
TABLE 2.16

Specific Activities in µc/gm at Time of Death in Samples of Femurs from Sheep and Dogs Exposed During the Underground Test

Group[a]	Animal Number	Time of Death or Sacrifice	µc/gm[b]
1	Dog 17	D + 2	0.0023
	" 22	D + 4	+
	" 16	D + 8	0.0007
	" 4	D + 9	+
	" 11	D + 9	+
	" 30	D + 70	0
	Pup C	D + 3	0.0169
	All Ewes (5)	D + 2 - D + 75	0
2	Dog 10	D + 4	+
	" 15	D + 4	0
	" 2	D + 8	+
	" 8	D + 9	+
	" 20	D + 10	+
	" 24	D + 70	0
	" 28	D + 75	0
	Pup B	D + 7	0.0012
	All Ewes (4)	D + 2 - D + 70	0
3	Dog 27	H + 32	+
	Ewe 19	D + 21	+
	" 22	D + 75	0
4	Dog 5	D + 2	0
	" 3	D + 4	0.0009
	" 9	D + 4	0.0008
	" 13	D + 4	0.0017
	" 31	D + 4	0.0012
	" 1	D + 10	0
	Pup A	D + 3	0.0074
	Ewe 13	D + 4	+
	" 24	D + 8	+
	Other Ewes (3)	D + 2 - D + 6	0
5	Dog 19	D + 4	+
	" 32	D + 70	0
	Ewe 20	D + 4	0
	" 25	D + 70	0

a. Groups designated as follows: 1. 8000 foot, surface exposed; 2. 5000 foot, surface exposed; 3. 5000 foot, foxhole exposed; 4. 2500 foot, surface exposed; 5. 2500 foot, foxhole exposed.

b. + indicates that planchet counts were detectable but below statistical significance; 0 indicates no detectable counts in the planchet.



a b c d

Figure 2.7. Autoradiographs Produced by Pieces of Femurs of Dogs Exposed During the Underground Test; a, b, c, Proximal Ends of Femurs of Pups A, B, C Exposed at 2500, 5000 and 8000 Feet; 38-day Exposure on Emulsion, 3 X; d, Head of Femur of Dog No. 17, 29-day Exposure on Emulsion, 3 X

2.3.5 Summary - Internal Radioactivity and Dosage Following the Underground Test

1. Total internal dosage assuming survival to H + 1000 hours for test animals was calculated to be less than 1 rep. Dose to lung tissue calculated in the same way varied from 0.10 to 8.83 rep.

2. Total quantities of radioactivity exclusive of bone and gut contents at sacrifice time were between 2.2 and 31.2 μc with a range in specific activities of 0.0001 μc/gm to 0.0016 μc/gm. At the same time total amounts of activity in lung tissue ranged from 0.007 μc to 7.44 μc with specific activities of lung tissue in the range of 0.0001 μc/gm to 0.0141 μc/gm.

3. There was no evidence that foxhole exposure positions afforded an appreciable alteration in total uptake of radioactive materials over surface exposure positions.

4. Radioactivity had diminished to undetectable amounts in many tissues by D + 9 and by D + 75 days had dropped below detectable levels in all tissues.

2.4 DEPOSITION OF PARTICULATE MATTER IN LUNGS AND OTHER TISSUES-AUTORADIOGRAPHIC EVIDENCE

Autoradiographic evidence of the deposition of radioactive contaminants was sought for both in the lungs and in other soft tissues. Since the total body quantities of radioactivity were of such low order in the tissues of animals exposed during the surface test no autoradiographs were made. Ten μ sections of soft tissues from animals which had relatively large amounts of activity following exposure in the underground test were exposed on Ilford G-5 nuclear track plates (see Appendix B for methods). After exposure times beginning at D + 7 days of from 27 days to 71 days duration all tissues except those of the lungs and bones were considered to be at background level. Attempts to find evidence of localized activity by means of differential grain counts were unsuccessful because of the extremely small amounts of radioactivity and the consequent small differences between background grain counts and grain counts underlying the tissue. Examination of samples of lung tissue was only mildly rewarding in that an occasional section revealed concentrations of activity as evidenced by clusters of activated grains.

PROJECT 2.7

Evidence of three types of particles, based on the reaction in the emulsion, could be distinguished beneath the lung tissue sections. In the examination under high dry and oil of 107 sections of lung tissues of both sheep and dogs a single specimen of a pure α emitting particle was found. Figure 2.8a and b are dark-field and bright field illustrations of the tracks originating from this particle. The mean track length, 20 μ, corresponds to the emission of α particles of 5 mev energy, therefore the particle is probably Pu^{239}, although Po^{210} can not be excluded. Total exposure time for the particle illustrated in Figure 2.8 was 47 days and about 400 tracks were produced in the emulsion during that time. The total number of disintegrations and the mass of the original particle were calculated as follows:

$$n = \frac{2\,C\,\text{[1]}}{\lambda \cdot t} \qquad (2.1)$$

where: n = number of atoms
C = observed track count
λ = disintegration constant for Pu^{239}
t = exposure time

substituting experimental values in (2.1) (2.2)

$$n = \frac{800}{(9.13 \times 10^{-13})\,(8.64 \times 10^{4})\,(47)}$$
$$= 2.164 \times 10^{8}$$

and this number of atoms represents a mass of

$$\text{gms.} = \frac{2.164 \times 10^{8}}{6.023 \times 10^{23}}\,(239) \qquad (2.3)$$
$$= 8.58 \times 10^{-14}$$

It is not possible to state whether the entire particle was made up of Pu^{239} or whether the mass calculated above was carried on a radio-inert fragment. A similar calculation may be made in the case of Po^{210}.

A second type of particle illustrated in Figure 2.9 was found only once after careful examination of the lung sections. This particle carried both β and α activity as evidenced by the presence of numerous granules and several α tracks in the underlying emulsion. Because of the proximity of the grains and the tracks it was assumed that both types of activity were carried together on a single particle although the dust grain was not seen.

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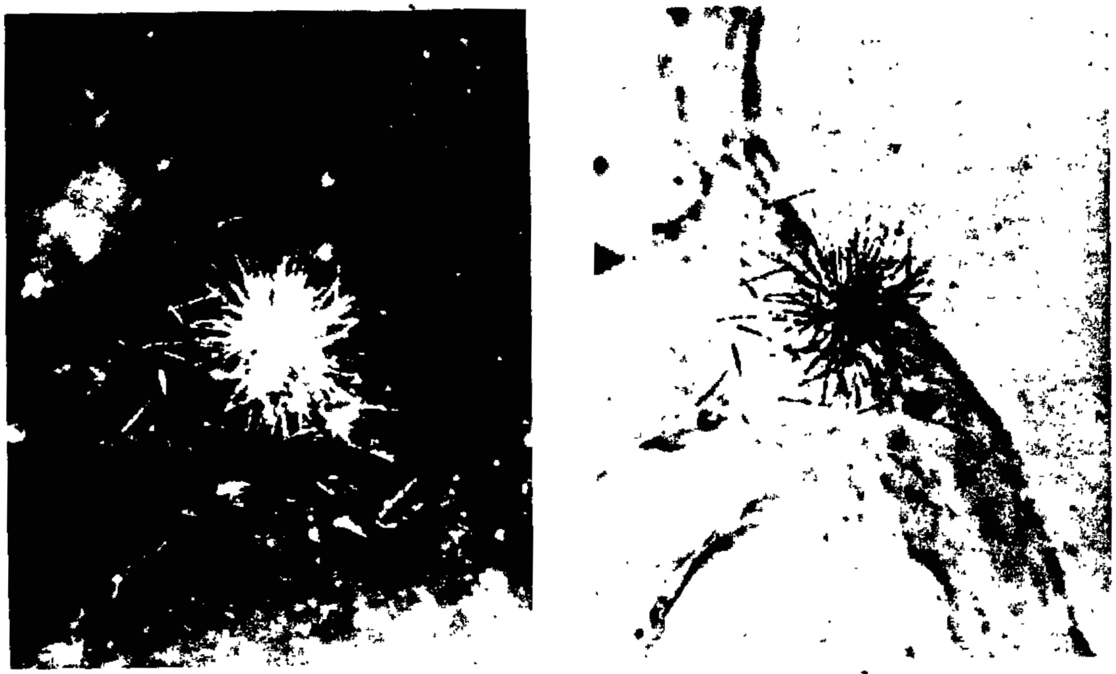
1. Yagoda, H., Radioactive Measurements with Nuclear Emulsions, J. Wiley and Sons, N.Y. (1949), p. 215.

PROJECT 2.7



a b

Figure 2.8. Tracks From a Pure α Emitting Particle Found in Lung of Ewe No. 4 Exposed at 2500 Feet During the Underground Test; a, Dark Field Illimination; b, the Same Track in Bright Field, 430 X

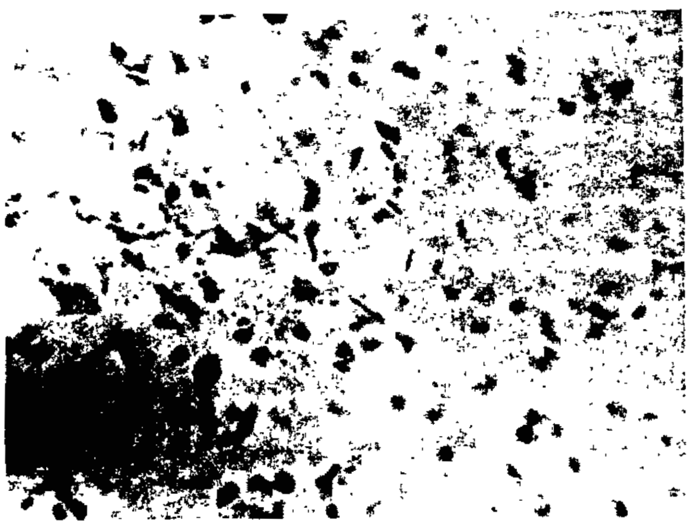


Figure 2.9. Tracks and Grains from a Mixed α and β Emitting Particle Found in Lungs of Dog No. 17, Exposed at 8000 Feet During the Underground Test, 430 X

The third type of particle found much more frequently in lung sections, is illustrated in Figure 2.10. The concentrations of grains were caused by pure β particle emission from sources which may differ in magnitude energy or half-life. The concentration of grains shown in Figure 2.10-b originate from a source which was either nearly spent by the time the preparation was made or which contained much less activity than was contained in the particle whose grain concentration is illustrated in Figure 2.10-c and d. In 107 lung tissue sections examined evidence of this third type of particle was encountered 55 times in the underlying emulsion.

Since careful study of autoradiographs was unrewarding generally even in the face of the fact that the lung tissue contained the largest amount of activity per gram when assayed by counting techniques, some explanation was sought for the discrepancy. Examination of lymph nodes, alveolar spaces and lung tissue revealed accumulations of debris containing crystalline particles 2 μ and less in diameter which could not be attributed to technique and which did not blacken the underlying silver grains. Particulate material of this sort must have been inhaled and must be either (1) particles which were no longer sufficiently active to produce a detectable image on the film or (2) those which had never carried radioactive components. It seems possible to explain the absence of a larger number of highly active particles in lung and lymph node radioagraphs on the basis of the following considerations. During an early phase following the detonation nearly all the components of the bomb are in a gaseous state. Shortly thereafter, as the mass cools, molten matter takes up a share of the radioactive debris. Somewhat later more radioactive material condenses out on the mass of fines which are in the vicinity and thereupon come into a somewhat loose association with these substrate particles. Thus it is possible for a flake of mica or other mineral to carry on its surface loosely associated radioactive particles, perhaps of molecular dimensions. If such particles reach the alveoli, the finely divided radioactive components might become dissolved off in the body fluids and be redistributed, leaving the inert residue. Studies of air-born particles[1] show that over 90% of the activity resides in particles above 10 μ in diameter. Such particles would not reach the alveoli in healthy lungs although they could be taken into the gut by swallowing. These considerations are of importance in dealing with the overall inhalation hazard. In addition it is estimated that the cloud may have contained an amount of air borne inert crater material of the order of 10^{10} grams while the fission product content was of the order of 10^3 grams.

If the type and condition of detonation were such as to raise either the total number or specific activity of the condensation-

1. Final report N.R.D.L. Project 2.5a-2.

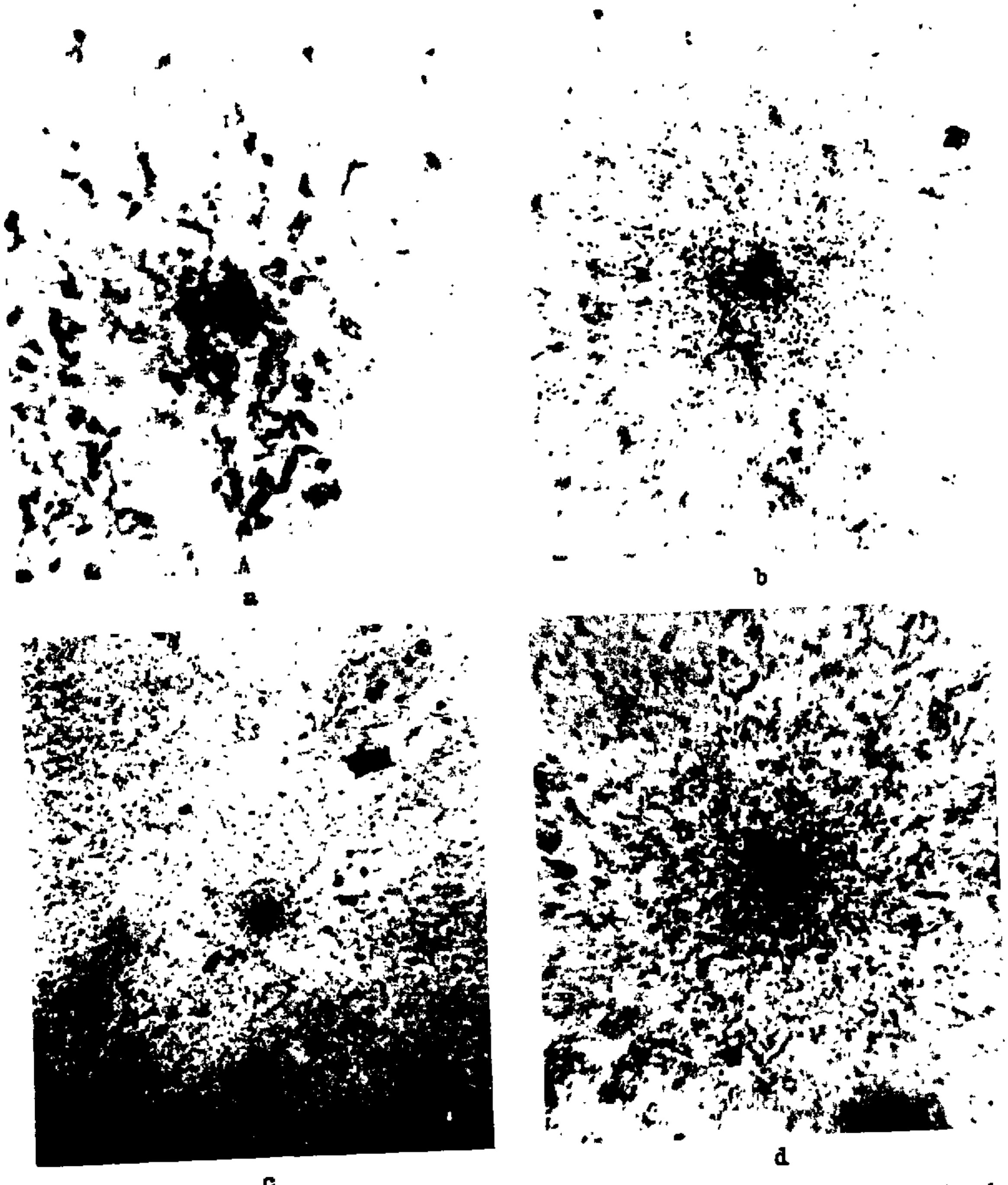


Figure 2.10. Autoradiograph Produced by a Pure β Emitting Particle in the Lung of Dog No. 7; a, Tissue Level; b, Emulsion at 10 μ Below Tissue, 430 X; c and d Autoradiograph Produced by β Emitting Particle in Lung of Dog No. 4, a-100 X, b-430 X

substrate type of particle between 8 μ and 0.5 μ in diameter, it is predicted that the inhalation hazard would increase. Condensation-substrate types of particles might be dealt with promptly by solution in the body fluids and thus result in a prompt redistribution of their radioactive components.

CHAPTER 3

DISCUSSION

Exposure of sheep and dogs during a surface or underground nuclear detonation was associated with the accumulation of a mixture of radioactive products within their bodies. The amount of such materials which may be taken up during an acute exposure is markedly dependent upon the concentration of radioactivity-bearing particles in the cloud and therefore the position of the animal during exposure. Wider distribution of airborne particles bearing radioactivity were associated with the underground shot than with the surface shot and the chances for the exposed animal to inhale contaminated materials were much greater at least up to 8000 feet from zero during the underground detonation.

Total activity in microcuries which theoretically could have been taken up in inhalation by an 8 kg dog (180 μc) during a 30 minute acute exposure and by a 45 kg sheep (900 μc) under identical conditions were 10 to 100 times the amounts which were found experimentally. This discrepancy results from the operation of several factors, among which the most important may be related to the concentration of the radioactivity in the inhaled debris during exposure. Differential fall-out data indicate that periods of high concentration of short duration occurred and therefore during 30 minutes the concentration of activity fluctuated. Experimental values for total activity given in Tables 2.10 - 2.11 do not include total activity within the gut.

Physiological response during the period of exposure might have been different from that postulated for a normal dog and sheep. No data are available relating to the respiratory response of an animal subjected to fluctuating concentrations of dust such as were prevalent during the underground test. It seems possible that the normal respiratory pattern would be greatly different under these conditions than when breathing normal air. Minor interruptions in the breathing response could effect appreciable changes in the total uptake during acute exposure. In the data presented it is felt that such factors as these could account for some of the variability.

Tissue sampling error and radio-assay may have resulted in calculations for total uptake that are too low. In defense of the method of tissue sampling employed it is pointed out that a more complete sampling per animal could only have been conducted at the cost of a reduction in the total number of animals exposed as well as reduction in sacrifice schedule. Radio-assay was carried on in the generally accepted manner and losses from the evolution of activity due to heating

the tissue samples to 500°C. could account for some of the indicated discrepancy. Generally, counting had to be conducted at near background levels due to the low activities.

Prediction of the biological effect of more powerful detonations than occurred in the surface and underground JANGLE tests may be made if due consideration is given to the assumptions and extrapolations which have been made in the results of the tests under discussion. A simple scaling factor cannot be found because of the complexity both of the respiratory process and the physical results of the detonation. The amount of earth moved into the air may be considered roughly proportional to the yield while the amount of residual activity will be closely proportional to the yield. If these assumptions are reasonable then the concentration in the cloud in microcuries per gram of particulate matter should not vary greatly with yield. The biological consequences of the higher yield detonation, aside from higher external radiation dose, will be due only to a larger cloud and the resultant increased exposure time. If it is assumed that the cloud diameter is proportional to the cube root of the yield a 20 fold increase would raise the inhaled activity by a factor of only 2.76.

In Tables 2.10 and 2.11 it was shown that the total radioactivity taken up averaged about 10 µc in dogs and 15 µc in sheep at the time of early sacrifice. If these values be raised to 15 µc and 20 µc respectively allowing a factor for error in sampling it remains that these quantities of material were retained in test animals during a 30 minute exposure. In the case of the higher yield detonation and assuming comparable conditions of exposure the inhaled activity in the average dog (8 kg.) would total about 41.4 µc while the sheep (45 Kg) might inhale as much as 55.2 µc. If the retention was comparable to that which prevailed in the JANGLE underground test this amount of radioactivity is estimated to correspond to about 0.9 rep (assuming an average of about 0.33 rep in the JANGLE test) while the dose to the lung tissue (assuming lung dosage to be about 3.62 rep in the JANGLE test) from inhaled materials would be of the order of 10 rep. The external dose, being correspondingly greater in the scaled test would be the dominant harard. The internal dose in the scaled test would be higher but insufficient to produce tissue damage over a short period of time. The possibility of a long delayed injury such as cancer resulting from a small amount of sharply localized irradiation from inhaled radioactive particles cannot be overlooked, although there are no data in the literature relating to such effects.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Biological injury resulting from a ~~1.2 KT~~ surface or underground nuclear detonation is predominantly due to total body external radiation. Sheep and dogs exposed at 2500, 5000 and 8000 feet from the zero points in both tests did not acquire by inhalation and ingestion physiologically significant quantities of radioactivity. Total internal dose due to the emission of β particles in animals exposed to the dust following the underground detonation was less than 1% of the external dose.

Estimates indicate that in the case of an underground detonation having a yield of 20 KT, the total internal activity in microcuries would be of the order of 2.76 times greater than in an underground detonation ~~having a yield of 1.2 KT, and therefore would give an internal dose of about 0.9~~ rep. However, the external radiation dose produced by contaminating detonations of the type in Operation JANGLE is overwhelmingly more important biologically up to 8000 feet from the zero point than the internal dose resulting from inhalation and ingestion of residual activity.

4.2 RECOMMENDATIONS

Long term survival studies on dogs or other large animals which have been exposed to the dust cloud following a contaminating detonation are required in order to evaluate the inhalation effects more completely. Repeated analyses of blood and urine during a long post-exposure period are necessary. Animals sacrificed after 12 to 24 months after exposure should be examined for evidence of pathology especially to lung, kidney and gut tissues.

Considerably more data are required on the early internal distribution of the inhaled and ingested radioactive mixture, which, when compared with radiochemical analyses of the contamination in specific organs will add greatly to an evaluation of the biological effects to be anticipated.

Additional experiments should be conducted in such a way as to permit an evaluation of the inhalation hazard independently from the external dose, since the latter may influence the degree of physiological response to inhaled radioactive contamination. Furthermore a clear separation of the contribution of the contamination in gut contents to

the total internal dose is needed.

In order to evaluate accurately the biological injury resulting from the inhalation of mixtures of fission products under the conditions existing in the JANGLE tests additional studies are needed in which activity and particle size measurements are closely correlated with biological data. These studies are particularly important for particles in the size range of $0.5\ \mu$ to $8\ \mu$.

APPENDIX A

TEST ANIMALS, EXPOSURE PROCEDURES AND AUTOPSY PROCEDURES

A.1 TEST ANIMALS

Sheep and dogs were selected as test animals during the JANGLE tests. Mongrel dogs of both sexes, approximately 1 year old were procured from a dealer at Bethesda, Maryland. Each was vaccinated against distemper, treated for ectoparasites and held in the laboratory for observation for about 10 weeks prior to the tests. The animals were healthy and apparently free of pulmonary disease prior to exposure. Attempts to have several pregnant female dogs in time for the test failed. Only one dog, No. 12, was pregnant at the time of exposure and since she was exposed during the surface test little could be learned about the uptake of activity by the fetus. Range in weight of the dogs at the time of exposure are shown in text Table 2.6.

Three puppies ranging in age from 3 to 8 weeks were exposed during each test in an attempt to compare the total internal activity with that of adult dogs. The results of this experiment are discussed in the text.

Two-year old ewes were purchased from a dealer in Utah. At least 20 of the 25 which were procured were apparently pure Suffolk while 2 appeared to be Rambouillet and 3 Suffolk crossed with Rambouillet. It turned out that many of the ewes were pregnant upon arrival and this was turned to advantage in obtaining data upon the uptake of activity by the fetal and maternal tissues. The range in weights of the sheep at the time of exposure as well as estimated length of pregnancy are given in Table 2.7.

A.2 ANIMAL EXPOSURE PROCEDURES

Three types of cages were developed for use in both the surface and underground test. The first type of cage, designed for use with dogs at 2500 foot arc is illustrated in Figure A.1. This type of cage consisted simply of a pair of wood "A" frames securely joined and braced. The bottom of the wire cage was at 30 inches above the ground and the top at 4 feet. Entrance was secured through a wire screen flap at the rear of the cage. Two by 4 inch by 6 foot base plates were secured at the ground by 30 inch steel stakes. A system of guy wires arranged as shown in the illustration guaranteed that the cage would not give way in the blast. A large safety factor was obtained with this arrangement because no blast effects could be found at any animal station. In some cases, cages placed at 2500 feet from under-

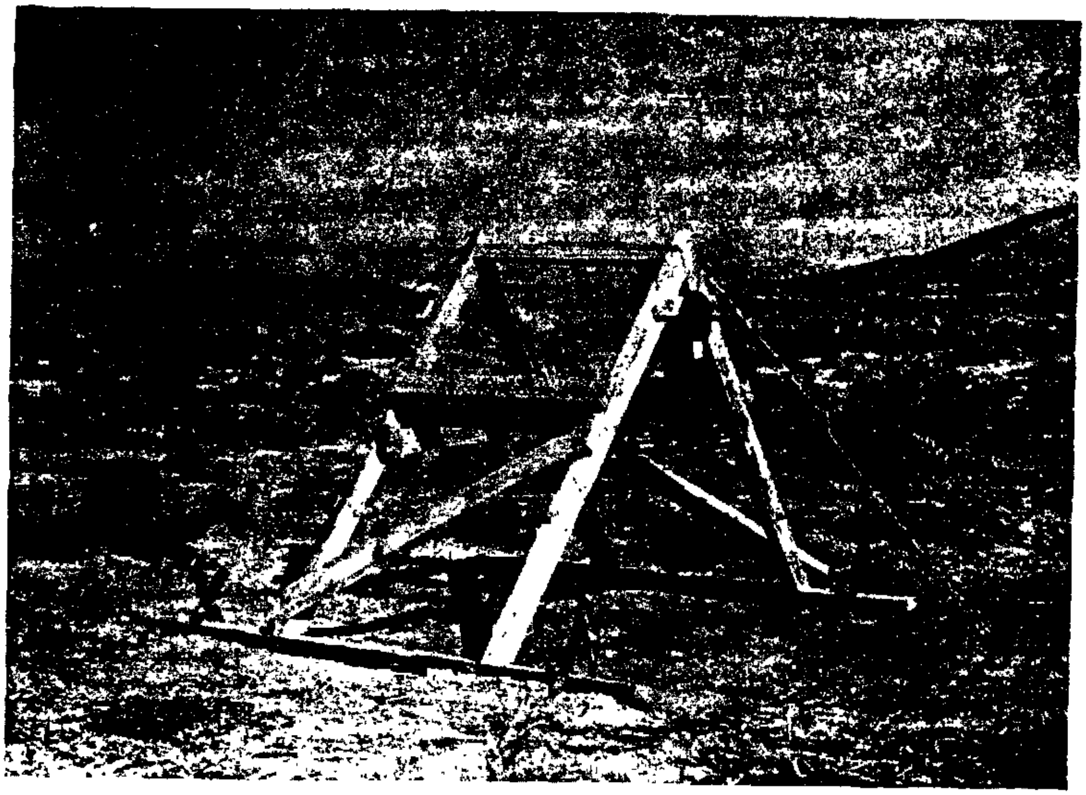


Figure A.1. Dog Exposure Cage As Used at 2500 Feet From Ground Zero in Both the Surface and Underground Tests

ground zero were not staked to the ground yet no evidence of blast effect could be found at the time of recovery. The second type of cage, used for dogs along the 5000 and 8000 foot arcs, consisted of braced wood "A" frames supporting the wire mesh cage at 30 inches off the ground level. Entrance to the cage was gained through a hinged door at one side.

Cages for sheep as shown in Figure A.2 were made from wood frames covered with screen wire and were 4 feet long, 28 inches wide and 30 inches high. A door at one end allowed access to the cage. Steel stakes and guys were used to secure the cage to the ground.

Modifications were made in the standard plywood lined foxholes in order to accommodate the animals. Figure A.3 illustrates the standard 2 by 4 by 6 foot foxholes with a ewe in place. Screen ends and top were added to the foxholes in order to prevent predators from entering as well as to reduce the amount of space in which the test animals could move about.

Prior to their being placed at their exposure stations, each animal was fitted with a harness made from 3/8 inch manila line. This

provided a useful sling with which to handle the animals in loading. In addition each animal was fitted with a blanket made from unbleached muslin. The purpose of the latter was to protect the pelt from fall-out as much as possible. The blankets were discarded at the time of the recovery of each animal. Each of the dogs was fitted with a wire muzzle in order to reduce the amount of ingested materials by preventing the dogs from licking themselves.

Test animals were distributed to their respective exposure stations as shown in Tables 2.1 through 2.4 at approximately H minus 8 hours for both tests. Total time during which the animals were in the forward area was about 12 hours for the surface test. Some of the animals (Tables 2.3 and 2.4) were recovered after 14 hours (H + 6) following the underground shot while the remaining animals were recovered at 26 hours (H + 24). Neither food nor water were furnished the test animals while they were at their exposure stations and those which were sacrificed during the first day after each test received no food between the time they were placed on test and their sacrifice.

A.3 AUTOPSY PROCEDURES

Both the ewes and the dogs were sacrificed by administering a lethal dose of phenobaribital sodium (50 mg per kg). The barbiturate

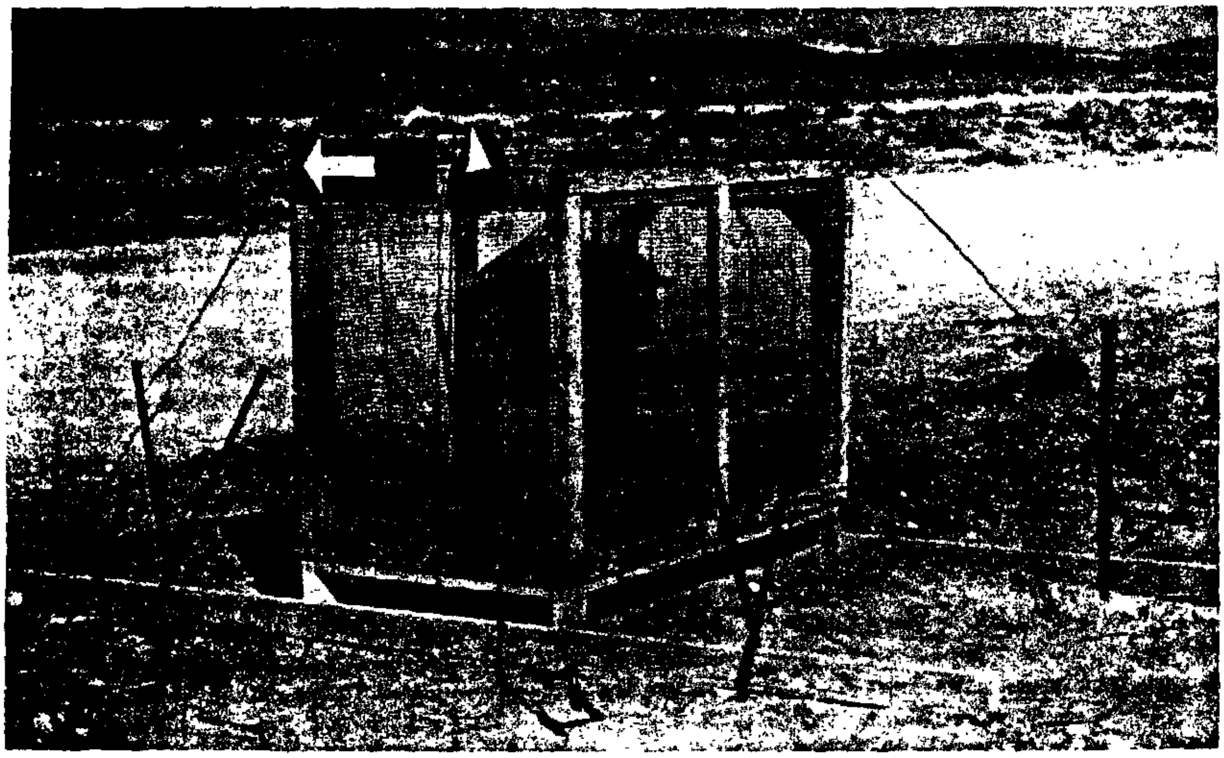


Figure A.2. Sheep Exposure Cage Used During the Surface and Underground Tests

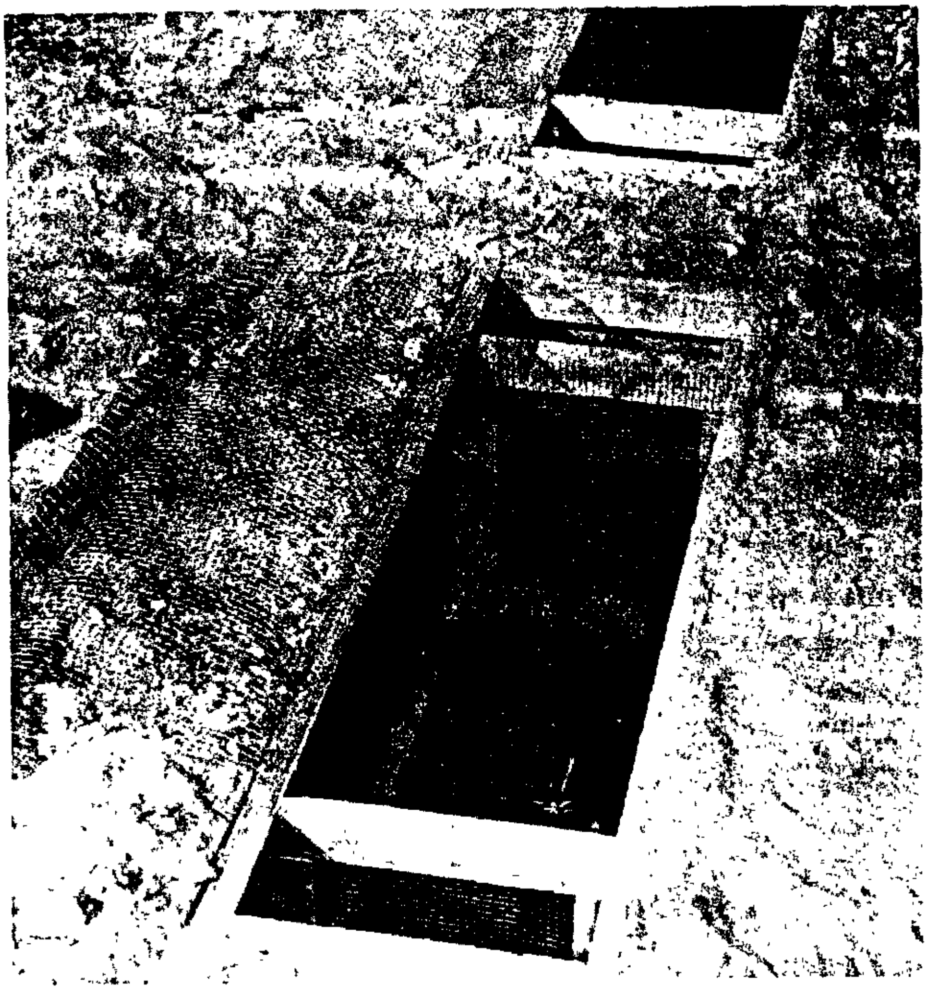


Figure A.3. Standard Foxholes Modified for Animal Exposures

was given intravenously and the dose proved to be very prompt in action. Upon the cessation of respiration a 5 ml blood sample was obtained and the animal was quickly exsanguinated. The autopsy followed immediately by opening the thorax and abdomen. Care was taken to avoid contaminating the underlying tissues with the pelt. The lungs were removed and dissected free of allied structures and weighed as promptly as possible. Several pulmonary lymph nodes were next obtained. Particular effort was made to remove the lymph nodes lying at the branching of the trachea. Other organs including the liver, spleen and kidneys were removed in turn and weighed. Wherever possible urine was taken as well as placental tissue and amniotic fluid. Fetuses were also taken when present. A portion of the femur was dissected free of musculature and allowed to dry for later study. When the autopsy was completed the carcasses were disposed of by burial under 4 feet of earth in a slit trench.

APPENDIX B

PREPARATION OF TISSUE SAMPLES FOR COUNTING AND AUTORADIOGRAPHY

B.1 PREPARATION OF TISSUE FOR COUNTING

Fresh pieces of tissue weighing from 0.5 gm to 1 gm were minced, placed in tared crucibles and heated to 500°C for 1 hour, in order to reduce their volume. Ashed tissues were removed from the crucibles by rinsing out with small quantities of absolute alcohol. Careful monitoring of the filtrate revealed no loss of activity to the alcohol. The ashed tissue was rinsed into specially constructed funnels provided with discs of filter paper upon which the tissue precipitated. Standardized planchets were made up from the charred samples and these were weighed in order to determine the quantity of material on each planchet. Bone samples were wet ashed with concentrated nitric acid.

B.2 CONSTRUCTION AND USE OF FREEZING-DEHYDRATION APPARATUS[1]

In preparing tissues for autoradiographs and pathological study it was felt that standard tissue techniques would not be reliable in the preparation of tissues suspected of containing contaminants. The strong possibility of displacement, solution and leaching during the course of preparation of sections by standard procedures gave rise to the design and application of the apparatus described here. Figure B.1 gives the specifications of the apparatus designed for use at the field laboratory.

In practice the tissue samples are quick frozen in the brass cups by immersion in a mixture of acetone and dry ice. Sufficient paraffin, to cover the piece of tissue is poured into the cup, allowed to solidify and fresh tissue added before the cup and tissue are placed in the chamber. The apparatus is then assembled and the vacuum pump[2] started. During the dehydration the inner thin walled chamber is maintained as near dry ice temperature as possible by means of a mixture of trichlorethylene and dry ice, while the plate on which the tissue cups are resting is maintained at -10°C. The latter is accomplished by placing the brass conducting legs in a dry ice alcohol mixture contained in 3 liter Dewar flask. Dehydration proceeds promptly because of the differential temperature between tissue and colder baffle; the short mean free path for the water molecules; leaving the tissue and

1. For details of a more elaborate apparatus and technique see Gersch, I, The Altman Technique for Fixation by Drying While Freezing. Anat. Rec. 53: 309, 1932.
2. Cenco-megavac capacity, 57 l/min.

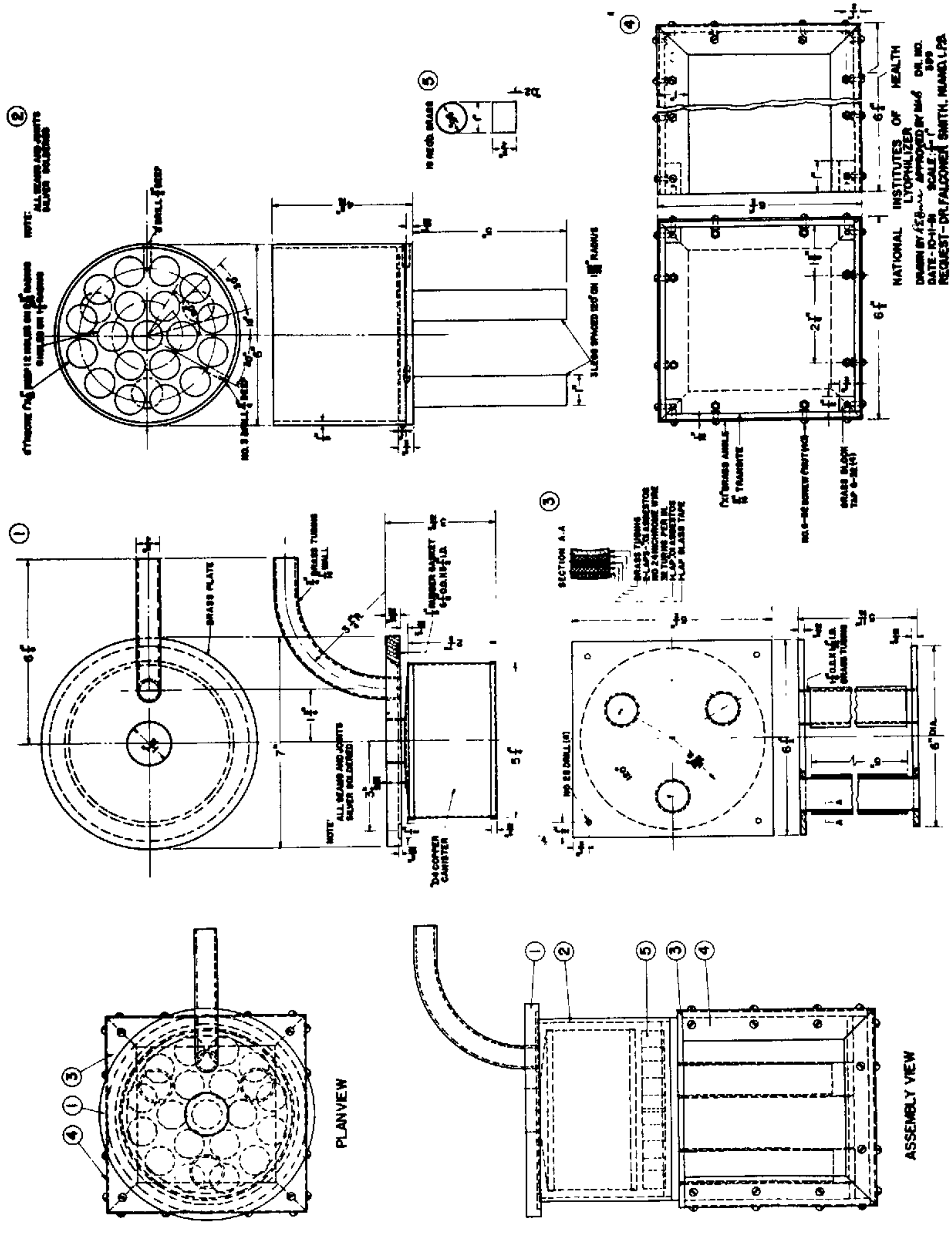


Figure B.1. Specifications of the Apparatus Designed to Fix and Embed Tissues by Means of a Freezing-dehydration Method

because of the continuous high vacuum in the dehydration chamber.

Experience has shown that under the above conditions even the most resistant tissues are thoroughly dehydrated in 6 hours. The infiltration and embedding is carried on by removing the apparatus from the alcohol-dry-ice bath and inserting the legs in a tube furnace (Figure B.1) and slowly bringing the temperature of the heavy brass plate to 70°C while continuing the high vacuum.

Well embedded paraffin blocks may thus be obtained about 8 hours from the time the fresh tissue is secured. Sections prepared from blocks made as described show excellent staining characteristics and minimal distortion. Tissue sections for pathological study were cut at 10 μ, stained with iron hematoxylin and counterstained with eosin. Autoradiographs were prepared from paraffin ribbons cut at 10 μ. Ribbons were floated directly on the emulsion out of warm absolute alcohol. After exposure the tissue sections were stained with metanil yellow and lightly counterstained with hematoxylin as described by Simmel. Autoradiographs were prepared at Bethesda where the possibility of extraneous radioactive contaminants was minimized.

APPENDIX C

Tabular Summary of Weather Data Pertinent to Animal Exposure During the Surface and Underground Tests

Date	Time	Temp. °C	Wind Direction	Wind Rate, mph
Surface Test				
~~9 Nov.~~[a]	0930	2.78	Calm	
	1030	2.78	160	3.5
	1130	6.10	160	4.6
	1230	10.55	140	6.9
	1330	12.78	140	5.7
	1430	13.30	140	14.9
Underground Test				
~~29 Nov.~~[b]	0530	-1.1	000	5
	0630	0	000	4
	0730	3.88	045	6
	0830	6.66	045	6
	0930	9.42	045	6
	1030	12.78	045	3
	1130	13.90	045	2
	1200	14.45	225	3
	1230	14.45 est.	225 est.	4 est.
~~30 Nov.~~[a]	0430	0	Calm	
	0830	2.78	Calm	
	1230	12.23	SE	6

a. Weather data from control point.
b. Observations made at underground zero.

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PROJECT 2.7

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